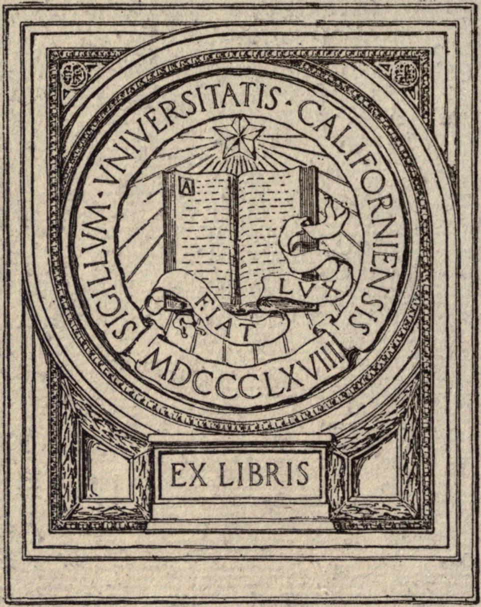
UC-NRLF

$B 103 275


SIGILLVM · VNIVERSITATIS · CALIFORNIENSIS
FIAT LVX
MDCCCLXVIII
EX LIBRIS

THE MANUFACTURE
OF
CARBIDE OF CALCIUM

BY

CHARLES BINGHAM, C.E.,

MANAGING DIRECTOR OF, OR CONSULTING ENGINEER TO, THE CALCIUM CARBIDE
FACTORIES AT NOTODDEN, THORNHILL, CORDOBA, MEXICO CITY, ETC.

WITH ILLUSTRATIONS.

UNIV. OF
CALIFORNIA

LONDON:
RAGGETT & CO.,
30, RED LION SQUARE, W.C.
1916.

[*All rights reserved.*]

TP770
B6

CONTENTS.

HAP. PAGE.
1. Chemistry - - - - - 1
2. Choice of Site - - - - 9
3. Arrangement of the Factory - - 14
4. Equipment - - - - 16
5. Electric Furnaces - - - - 20
6. Construction of the Furnaces—The Body 37
7. The Bottom Electrode Holders - - 40
8. The Upper Electrode Holders - - 44
9. Crushing Apparatus - - - 57
10. Screeners for Carbide - - - 61
11. Transport Appliances - - - 63
12. Laboratory - - - - 65
13. Drum-making Plant - - - 70
14. Limekiln - - - - - 73
15. Materials of Manufacture - - - 78
16. Results of Manufacture - - - 109
17. Power Plant - - - - 117
18. Limekiln - - - - - 127
19. Furnaces - - - - - 132
20. Heat Losses in Furnace - - - 150
21. Power Factor - - - - 165
22. Electrode Consumption - - - 174
23. Packing - - - - - 179
24. Testing of the Carbide and Quality - 185
Tables - - - - - 208

358214

LIST OF ILLUSTRATIONS.

Fig.			Page.
1.	Corroded Electrodes - - - - -		2
2.	Corroded Electrode - - - - -		3
3.	Plan of Factory Lay-out - -	*To face*	14
4.	Elevation of ditto. - -	,,	15
5.	Elevation of ditto. - -	,,	15
6.	Plans of Factory Lay-out - - - -		17
7.	Electric Furnace, single-phase - - -		20
8.	Do. do. - - -		20
9.	Do. three-phase - - -		21
10.	Do. do. - - -		21
11.	Zone of Fusion - - - - -		22
12.	Electric Furnace, covered in type (new) - -		32
13.	Do. do. (old) - -		33
14.	Do. Horizontal Electrodes - -		34
15.	Section of Bottom Electrode Holder - -		40
16.	Upper Electrode Holder, Siemens' type - -		44
17.	Do. do. Swedish do. - -		44
18.	Do. do. Italian do. - -		45
19.	Do. do. Swedish do. with Central Wedge		46
20.	Do. do. American type - -		48
21.	Do. do. French do. - -		49
22. 23. 24.	Do. do. Various types - -		49
25.	Cranes for Upper Electrodes - - -		54
26.	Do. do. - - -		55
27.	Apparatus for Phosphorous Test - - -		68
28.	Carbide Drum, American type - - -		70
29.	Do. European do. - - -		71
30.	Do. Lever-lid top - - -		71
31.	Lime Kiln, Contact type (old) - - -		74
32.	Do. do. (modern) - - -		75
33.	Do. Gas Fired type - - - -		76
34.	Arrangement of Conductors - - - -		154
35.	Diagram of Furnace Heat Losses - - -		160
36.	Characteristic Curves of Furnace - - -		171
37.	Do. do. - - -		173
38.	Table showing Volume Changes due to Pressure and Temperature - - - - -		193
39.	Diagram of Production and Gas Yield - -		195

CHAPTER I.

CHEMISTRY.

In a work devoted primarily to the commercial side, *i.e.*, the manufacture, of a product, it may scarcely be thought necessary for the author to dip too deeply into the purely scientific aspect of the question, especially when a host of the foremost chemists of the age have devoted time and labour to investigating the numerous problems associated with the formation of the product in question. If the writer ventures to touch upon the purely chemical side, it is merely with the object of mentioning certain phenomena, the study of which may lead to improvements in an important commercial factor, viz., the consumption of electrode carbon.

From the time when Moissan published his classic investigations and Willson applied for his classic patent, the accepted equation for the production of calcium carbide in the electric furnace from carbonaceous matter and lime has always been:—

$$CaO + 3C = CaC_2 + CO.$$

Is this formula the correct one? The final result may be approximately the production of the two compounds, CaC_2 and CO, but the reaction, or rather reactions, which take place before this final stage is reached, certainly appear to be far more complex; the conversion of the raw material into carbide appears to take place in steps.

In Figs 1 and 2 are reproduced photographs of two electrodes, one from Norway, the other from Mexico, which, in technical phraseology, have burnt badly.

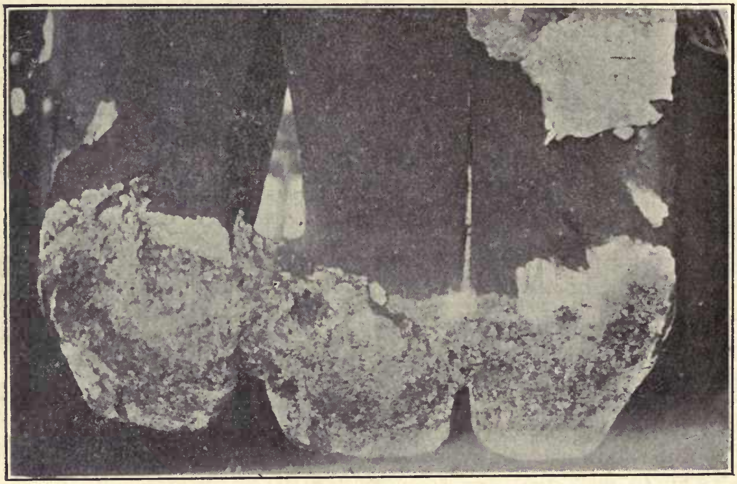


Fig. 1.

In both cases the carbons were of poor quality, their chief failing being excessive softness. Both sets show the characteristics of soft carbons, viz., the wearing away to a point at the lower ends and bad corrosion between the pairs of electrodes, the corrosion being most marked between the pair of carbons farthest removed from the busbars which conduct the current from and to the transformers.

The condition of these carbons gives food for thought in a large number of directions, when studying the question of the reaction or reactions leading to the formation of calcium carbide.

Why, for instance, do the electrodes assume a pointed shape at the lower ends? If, as is generally assumed,

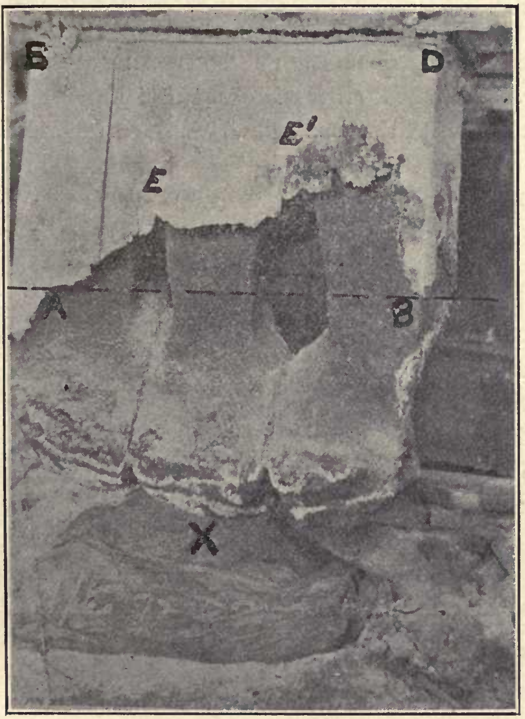


Fig. 2.

the corrosion is due to a part of the electrode being used up in supplying carbon for reducing the lime, why is it that the central part of the carbon is not eaten away first?

It may be argued that, as these sets of carbons were both used with alternating current, skin effect comes into play and that the most violent action takes place, not underneath the centre of the carbon, but round its periphery. Against this must be set the fact that carbons, used in the writer's presence in furnaces fed with direct current, also wore away considerably more at the edges than in the centre.

Again, what causes the carbons to be eaten away so badly about a foot (30 cm.) above the lower ends? It should be noted that the carbons were entirely immersed in raw material to a depth of about a foot (30 c.m.), as shown by the dotted lines A B in Fig 2, so that the curve of corrosion begins about 6 inches (15 c.m.) below the surface of the mixture.

Gin attributes the corrosion to the oxygen which is liberated when the CaO is split up; if this view be correct, it is clear that the other writers (the great majority) are wrong, when they state that the reaction is a single one, or in other words, that oxygen from the lime forms CO at the same moment as the Ca from the lime combines with the 2C to form the carbide.

Very many observers attribute the corrosion of the sides to the action of air upon the carbons, owing to the latter being raised to a high temperature by the heat set up, firstly by the combustion of CO on the surface of the charge, secondly by ohmic resistance, and thirdly by the heat conducted from the hot zone by the carbons themselves.

Several phenomena would appear to favour this theory. Hutton & Petavel have pointed out that if the carbon is completely buried in the raw material and the furnace made completely gas-tight, so that no air can enter, there is very little consumption of the carbons.

Another point in favour of this theory is the undoubted fact that, in practical work with open furnaces, the corrosion will always be found to be greater in the carbons of a furnace near an open door or window than in one farther away, and the corrosion is more marked when wind is blowing in at the door or window.

But there are, on the other hand, certain other points which appear to controvert this theory. In the first place, the photographs show that no corrosion at all appears to take place on the narrow sides of the electrode, although these sides are certainly as hot and, where the lagging has disappeared, as much exposed to the atmosphere as the broad side which is so badly eaten away.

The explanation why the corrosion takes place in two distinct places may be as follows. According to the experiments of Ruff & Goecke (Zeitschrift für Elektrochemie, 1/3/12), lime boils at 1995°C. and is completely volatilised at 2009°C. It is therefore clear that when the temperature of about 2000°C. is reached dissociation of the lime takes place, and it is practically certain that this temperature is reached before the lime has sunk to the level of the lower end of the top electrode, for repeated measurements have shown that the temperature at the end of the upper carbon is about 3200°C.

On the other hand, it seems equally clear that dissociation of the coke or anthracite (which always contains oxygen, hydrogen, nitrogen, silicon and other impurities) does not take place until a lower level has been reached.

More than one carbide expert has indeed pointed out that first of all the lime melts—by which is probably meant that the lime is reduced and metallic calcium is formed—and that the coke or coal can then be seen melting in this molten bath.

The writer therefore believes that there must be two distinct reactions. First the lime is reduced as stated at a point above the level at which the carbide is formed. Most of the oxygen thus set free naturally combines with a portion of the carbonaceous part of the charge, but a portion must envelope the electrode, and this oxygen must be the agent which commences the corrosion along the sides of the carbons. This corrosion will probably be accelerated by combustion of CO at the level of the surface of the raw material. In a completely closed furnace—as Hutton and Petavel point out very clearly—there is no upward draught causing the oxygen to follow a path along the carbons. Consequently the oxygen will spread in the furnace and will combine more readily with the softer anthracite or coke than with the electrode carbon. This may also be the reason why the electrode consumption in a modern closed furnace is lower than in an open one. The oxygen may be forced to follow the line of the draught, and the draught is, of course, so arranged as to divert the gases away from the electrodes.

The second reaction is the dissociation of the coke or anthracite, which probably takes place simultaneously with the formation of the carbide. Both coke and anthracite contain appreciable quantities of impurities, including oxygen, the latter fuel, of course, containing much more oxygen than coke does. This oxygen is liberated below the bottom end of the top electrode and the natural path of a portion of it would be along the edges of the upper carbon, which, on its journey towards the surface, it would lick away, forming CO and giving the pointed or rounded shape to the bottom ends of the carbons. This view, if correct, would also explain why the electrode consumption with anthracite is always higher than with coke (see later on).

Another question which seems to deserve investigation is what effect the considerable quantity of hydrogen present in anthracite has upon the electrodes.

It seems hardly possible that the hydrogen can escape uncombined to the surface of the raw material and be burnt there to form water or steam. It seems rather to be probable that the extremely high temperature of a carbide furnace may cause the hydrogen to combine with carbon, for instance, to form marsh gas (methane).

If high temperature is the chief factor in bringing about this combination, the hydrogen would probably attack the lower end of the upper carbon, the temperature of which is undoubtedly higher than that of any part of the furnace charge. Experiments seem to show that there is a large production of marsh gas when anthracite in especial is used, but as the anthracite itself is shown by the analysis to contain a considerable quantity of this hydrocarbon, it is possible that no additional quantity is formed by the hydrogen from the coal.

There is also apparently a further factor at work tending to eat away the bottom ends of the electrode. It has been stated by several authorities that at very high temperatures (by which is apparently meant temperatures exceeding 2000°C.), CO dissociates.

In answer to an enquiry addressed by the writer to Mr. Ruff (see later on), the latter stated that at the very high temperatures actually measured by him he had indeed noticed no tendency on the part of the CO to dissociate, but he had, on the other hand, remarked that there was an apparent tendency for this gas to take up an additional atom of C and become therefore equivalent to C_2O.

It is evident that this absorption of additional carbon being essentially due to very high temperature, it will preferentially take place where the re-agents are hottest, and as the lower end of the bottom electrode contains the hottest carbon in the furnace, it is probably quite natural that this should form, at any rate, partly, the source of supply of the carbon needed not only to provide for the oxygen liberated from the anthracite or coke, but also that required for the additional atom of C in the C_2O.

One more phenomenon may be alluded to, which the writer has never seen mentioned in any of the numerous papers on electric furnaces, but which seems worthy of further investigation, viz., the fact that the gases seem to strive vigorously to follow the path of the electric current whenever possible. The writer noticed, in connection with experiments made in 1899 with a Moissan furnace, that the gases appeared to follow the line of the electrodes, and he had an experimental furnace constructed with a horizontal upper electrode and the usual bottom electrode. The upper electrode had its working end not in a vertical line above the bottom electrode, but at an angle of approximately 45° to the vertical axis of the bottom electrode. The top of the furnace was completely open so that the natural path for the escape of the gases was through the raw material in a vertical line above the bottom electrode, but it was found that they followed the oblique line from the bottom to the top electrode. Indeed, the gases were found even to escape in a large measure through the opening in the side wall of the furnace, this opening being somewhat wider than the electrode itself.

CHAPTER II.

CHOICE OF SITE.

The paramount consideration in choosing the site for a carbide factory is the necessity of making returns on the capital invested. To realise this object, it is clear that the factory must be so situated as to be able to manufacture at a figure which bears at least as favourable a proportion to the nett selling price as is the case with its competitors.

Of course, the fact must not be overlooked that in some special cases the chief factors which make for cheap production, and which are enumerated later on, may to a great extent be set aside, as they may be more than counter-balanced by a high protective duty; by high freights from competing factories; by the existence of a government-granted monopoly; or by other similar causes.

As regards advantages of this nature, which have little or nothing to do with the actual manufacture, the author will only say that in his experience advantages, such as high protective duties, however effective they may prove to be in the case of the *older* countries, which have highly developed industries and efficient means of distribution, have never yet stopped the importation of carbide into the *newer* countries. Either the higher cost of manufacture in the newer countries, or the difficulty of locating the factory near a seaport, so as to ensure cheap distribution of the manufactured product, may, to a great extent, put it out of the running.

In order to make his meaning more clear, the author will instance Argentina. Electricity generated by coal or oil being altogether too dear in that country, the nearest available waterfall was selected. But this waterfall is some 400 miles from the sea-coast and from the chief centres of consumption. Consequently those raw materials, say more than half, which have to come from Europe, must be railed up to the factory and the carbide has to be railed down. These costs, added to the high charge for labour usually prevailing in the newer countries, make it possible for European carbide to compete with success, and, indeed, to secure the bulk of the trade, although the import duty amounts to pretty nearly half the value of the imported article.

The numerous projects always being put forward for the manufacture of carbide in the newer countries should receive the most searching investigation in view of what has been said in the preceding paragraphs. It will rarely indeed be found that they will bear the scrutiny of an impartial carbide expert.

Apart from the political considerations mentioned above, the chief factors for successful manufacture (always, of course, presuming good management obtains) are mentioned below in what the author considers their order of importance:—

1. Efficient design of the factory and plant.
2. Cheap electric energy; (here let it be said that current supplied during a part of the day only is usually dear at almost any price).
3. Pure and not too dear limestone or lime.
4. Pure and not too dear carbon, in the shape of coke or a high-carbon coal.

5. Cheap labour (by which we mean labour, which whether cheap or dear per hour, is cheap per ton of carbide produced).

6. Proper facilities for distribution of the carbide.

7. Electrode carbons of good quality at a reasonable price.

Of course, it is clear that the dearness of one particular factor will not matter much if it is counteracted by the cheapness of another factor, for it is certain that at the present time no carbide factory exists which is not in a position of inferiority, as regards at least one of the factors, to at least one other factory.

In order to be able to judge whether our proposed factory is favourably situated or not, let us consider the amount required of each of the various factors, and what is a low and what is a high price for it at one or other of the various existing factories.

1. Cost of factory (we assume that the factory is a properly equipped one, not one which has to have its materials wheeled about in wheelbarrows, or to purchase its drums and similar goods outside)—capital outlay, £4 to £20 per horse-power installed, costing at an average of 12½% for interest and depreciation, 10s. to £2 10s. per ton of carbide per annum.

2. Cost of electrical energy, £1 to £5 per electric horse-power and per year of, say, 365 days (8,760 hours). Assuming that one e.h.p.-year will, after making all allowances for loss in leads, in transformers, for crushing, lighting, transport appliances, pumping, etc., also for stoppages, through accidents, strikes, etc., produce 1¼ tonnes of packed carbide, the cost for energy per

metric ton will therefore vary from 16s. (fr. 20) to 80s. (fr. 100) per tonne of carbide.

3. Lime—cost per metric ton (1000 kilos), 7s. to 35s. (fr. 8.75 to 43.75). Assuming a consumption of 900 kilos per 1000 kilos of carbide, the cost will therefore be 6s. 3d. (fr. 7.90) to 31s. 6d. (fr. 39.50).

4. Coal or anthracite coal or charcoal, of first-rate quality—cost 9s. to 40s. per tonne. Assuming a consumption of 600 kilos per 1000 kilos of carbide, the cost will be 5s. 3d. (fr. 6.60) to 23s. 4d. (fr. 29.50).

5. Labour—cost per tonne of packed carbide, 12s. to 25s.

6. Carbons for electrodes—cost for ordinary carbons, as distinguished from those made of artificial graphite, including carriage to factory and, in some cases, import duty, 180s., (fr. 225) to 400s. (fr. 500) per tonne. Assuming a consumption of 20 kilos per tonne of carbide, the cost will vary from 3s. 7d. (fr. 4.50) to 8s. (fr. 10) per metric ton of carbide.

7. Cost of distribution.—It is evident that this will depend upon the facilities which the factory has for getting its product to the market it is intended to serve.

As already stated, no existing factory has the advantage of the lowest figure for each and every item mentioned above. Consequently the author gives below the figures for a well-known factory which in normal times, when there is no outrageous price-cutting through over-production, as has so often been the case, can hold its own in the general export trade.

Cost per metric ton of unpacked carbide for the chief factors only :—

	£	s.	d.
Electric energy	1	3	3¾
Lime		18	7¾
Coke or anthracite		15	7½
Carbon for electrodes		6	1
Labour and Management ...	1	0	10
	4	4	6

Of course, the above figure takes no account of rent or cost of factory, machinery, etc., and, as will be seen later on, does not therefore by any means represent the full cost of production. It is given simply to show the maximum amount which the prospective manufacturer can afford to expend upon the five items mentioned, unless some special consideration, such as high protective duty, allows him to spend more, and in considering the last-mentioned point, he will do well to examine more carefully whether this other consideration is not neutralised by something else.

For instance, the man at the Victoria Falls may think that he can produce carbide at £2 per ton more than the cost in Europe (a belief which would probably prove expensive to his shareholders), and that the import duty of 15% (say 36s. per ton) and the freight from Europe (say 35s. per ton) in total 71s. per ton, would far more than offset his increased manufacturing cost of 40s. per ton.

But would it? He would probably find that as the foreign article has been first imported and stored at the seaports, and as the importers have their business houses there, the chief centres of consumption are far nearer to those ports than to his factory, and that it costs him 60s. to 80s. per ton more for railing his product than the imported product pays.

CHAPTER III.

ARRANGEMENT OF THE FACTORY.

In the past every person who had a cheap water-power available, believed he had the alpha to omega for making cheap carbide, even if there were no limestone or carbon within hundreds (or even, as regards coal, thousands) of miles. To-day it is beginning to be recognised that even the extra cost for running a badly designed factory will completely neutralise the advantage of cheap electric energy.

The author may compare two factories actually known to him. One cost £14 to build and equip for each ton of productive capacity per annum; the other cost £4. Consequently, at 12½% for interest and depreciation, the dead cost per ton of carbide is in the one case 35s., in the other 10s. At the dear factory the power is 8s. per ton of carbide cheaper than at the cheap factory, so the latter can compete successfully with the former, in spite of the former's cheaper power. This statement, of course, presupposes that the equipment is equally good in both instances. This is the case; in fact, the advantage in this respect rather rests with the cheaper factory.

As a general rule, it may be taken that heavy expenditure on buildings is totally unnecessary. While the general tendency in England is to spend too little on factory buildings, thereby making them cramped and unsuitable for comfortable working, the other extreme is usually gone to on the Continent, and the various buildings there are often on so "monumental" a scale

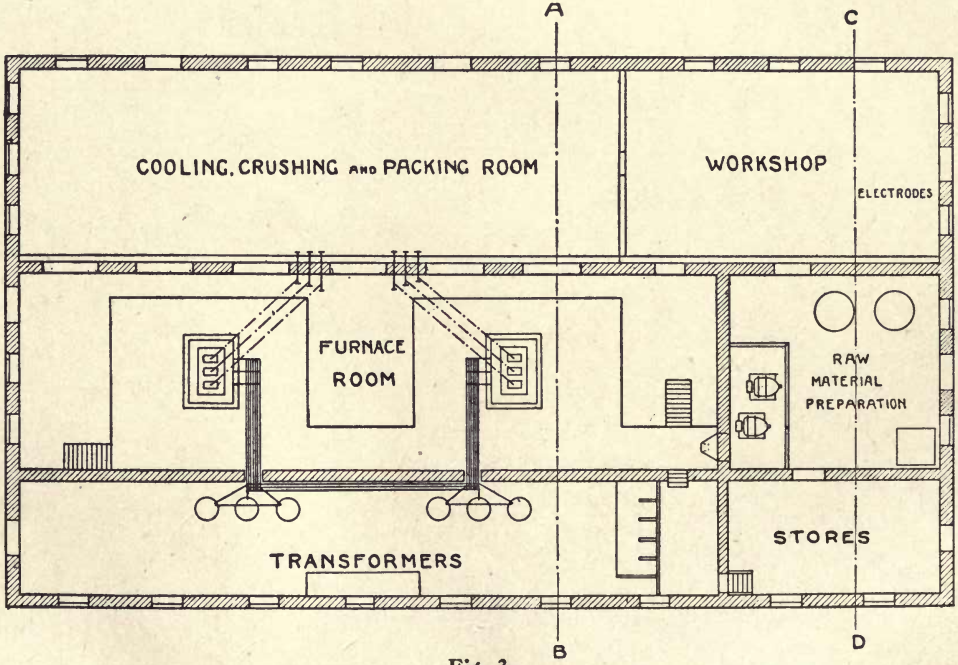

A
C
COOLING, CRUSHING AND PACKING ROOM
WORKSHOP
ELECTRODES
FURNACE ROOM
RAW MATERIAL PREPARATION
TRANSFORMERS
STORES
B
D

Fig. 3.

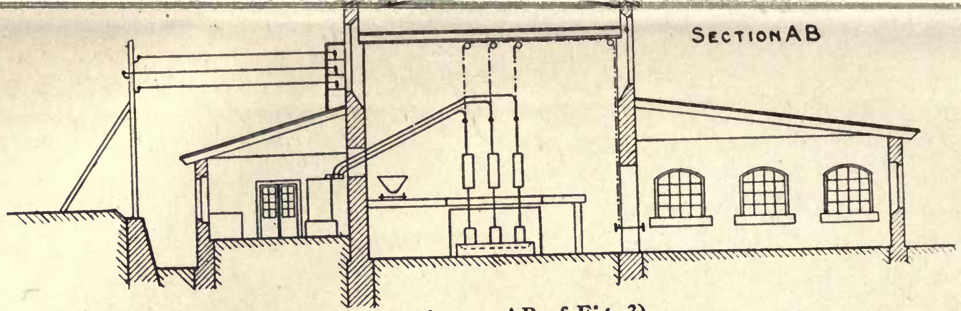


Fig. 4 (Section on AB of Fig. 3).

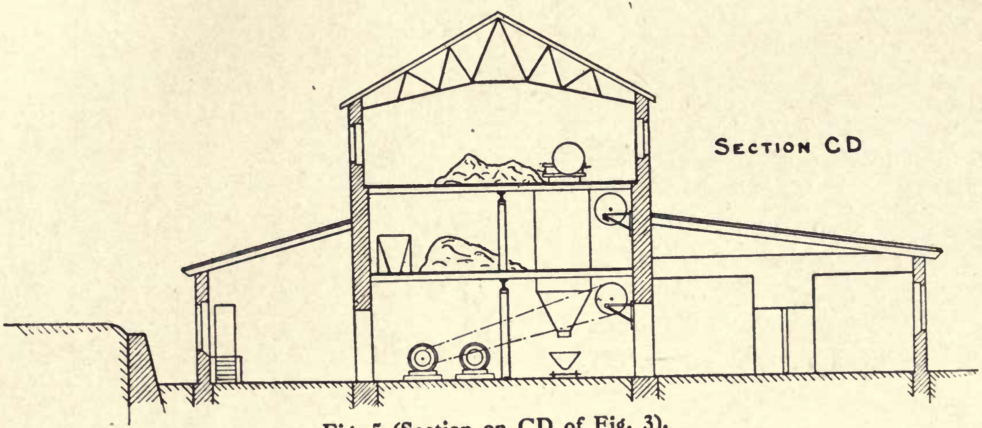


Fig. 5 (Section on CD of Fig. 3).

that workmen and managers have to cover three or four times as much ground as is necessary.

The general design of the factory will, of course, vary in nearly every instance. One factory will have its limestone quarry in its backyard and will bring the stone to the kiln by an overhead wire line. Another will have to bring it in by water and consequently have to provide a quay, with cranes and elevators.

One factory, again, will have to lay in a stock of coke or anthracite to last for half a year, and will consequently have to provide silos or other suitable means for storing the coke or coal and for taking it as required to the crusher, so as to avoid all unnecessary expenditure for labour; another will draw its coke from coke furnaces, perhaps half a mile away, and will dump the coke direct from the cart or trolley into the crusher or into the elevator leading to the crusher.

The circumstances vary so greatly that it is impossible to give anything here serving as a general guide. Plans of the lay-out of two factories are, however, given here. (Figs. 3, 4, 5, and 6.) In both cases the author is of opinion that too much money has been spent on the buildings and that a much better arrangement could have been secured, for less capital expenditure, and a saving secured both on the bill for depreciation and interest and for labour.

Good modern practice in a well-designed factory requires that, with reasonably efficient workmen, not more than 14 workmen should be required in small factories for each 1,000 tons of saleable carbide produced, and not more than 10 in large factories, these figures including the men required for burning the lime and for making the carbide drums.

CHAPTER IV.

EQUIPMENT.

Naturally the first item of the equipment of a carbide factory which has to be considered is the supply of power or electric energy.

This energy, in the case of almost every carbide factory in existence, is supplied from a hydro-electric station, *i.e.*, a station where the prime mover, or force, is falling water; in other words, a waterfall. This falling water passes through turbines or Pelton wheels, and the outfit will vary enormously, according to whether the fall is high or low and according to the belief of the designer of the station in the one or other type of turbine or water-wheel.

Equal variety will be found in the dynamos, or electric generators, which are driven by the turbines or water-wheels; indeed, it is safe to say that the plant for generating the electricity is not exactly similar in any two carbide plants in existence. This variety is due not only to the continual improvements effected in the machines themselves, especially in the electrical part of the plant, but in even greater measure to the conditions being different in almost every case.

There is, therefore, no object in describing a typical hydro-electric station supplying current to a carbide factory, for the description might totally mislead the seeker after information; in other words, he might be led to adopt something unsuitable through his conditions

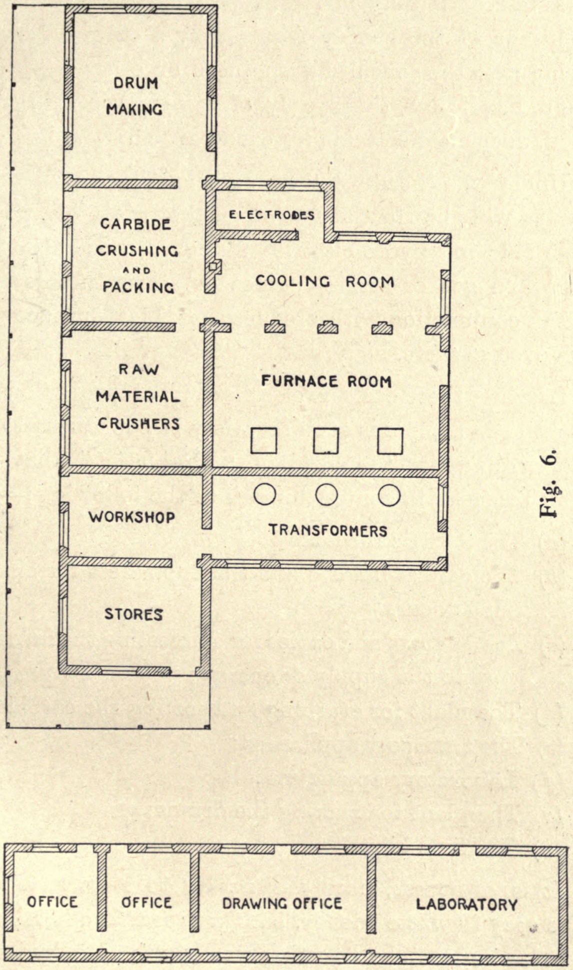

DRUM MAKING
CARBIDE CRUSHING AND PACKING
ELECTRODES
COOLING ROOM
RAW MATERIAL CRUSHERS
FURNACE ROOM
WORKSHOP
TRANSFORMERS
STORES
OFFICE
OFFICE
DRAWING OFFICE
LABORATORY

Fig. 6.

being totally different. We must therefore confine ourselves to ascertaining as far as possible the nature and conditions of the supply required by a carbide factory, leaving it to the consulting engineer or other expert to design, or arrange, the supply of the electric energy in the manner most suitable for each particular case.

Under the heading "*Power Plant*" a number of figures will be found showing the cost of power generated in hydro-electric stations, and also the cost when gas or steam-engines or steam-turbines are used in conjunction with producer gas, blast-furnace gas, coke-oven gas, etc.

Leaving, therefore, the electrical plant proper out of consideration, there is such a variety of appliances to be dealt with under the head of "*Equipment*" that the writer proposes to confine himself to the following;—

(*a*) The electric furnaces;
(*b*) The carbon-holders and the appliances for changing them;
(*c*) The busbars and cables for connecting the furnaces up to the supply of energy;
(*d*) The plant for crushing and sorting the carbide;
(*e*) The transport appliances;
(*f*) Laboratory appliances;
(*g*) The plant for making the drums;
(*h*) The lime kiln.

It is, of course, hardly necessary to state that it is quite easy to waste money, both as regards capital cost and running cost, by selecting wrongly the hundred-and-one other parts of a carbide plant required in addition to the chief appliances mentioned above. A full description of the various minor appliances in use would, however, make this work far too long. The author will merely make a short contrast, as in the case of the lay-out of the factory.

In the one case, a most elaborate system, costing thousands of pounds, is in use for handling the raw materials. These are first dumped into the hoppers of the crushing machines, then carried by an elevator to a mixer; then by another elevator to automatic weighing machines, which proportion the quantities of lime and coke; then by another elevator to a horizontal conveyor, which finally delivers the raw material (in a more or less mixed condition, generally requiring re-adjustment) at the furnaces.

In the other case, a very simple arrangement, worked by one man per 1,000 tons of carbide produced, brings the coke and lime in the proper proportions to the hopper. There is only one elevator; everything else is done by gravity feed, probably the least costly system to instal and to work known.

CHAPTER V.

ELECTRIC FURNACES.

It will hardly be necessary to deal with the types of furnace which belong to ancient history; descriptions of them can be found in the text-books referring to acetylene.

In Europe to-day, with the exception of two small factories, no other than tapped carbide is produced, and the two types of furnace in most general use are those having one or more upper electrodes and one bottom electrode (Figs. 7 and 9), and those having connected top electrodes only (Figs. 8 and 10).

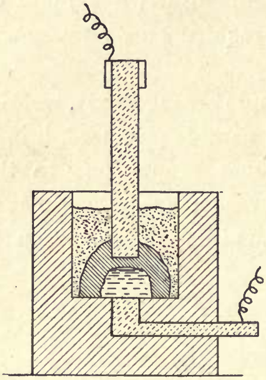


Fig. 7.—Single-Phase.

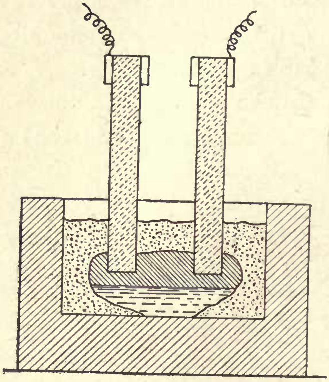


Fig. 8.—Single-Phase.

It is, of course, clear that in furnaces of the types shown in Figs. 8 and 10 the molten material in the furnace itself will, as soon as it has formed, become the idle bottom electrode. This point is important to note because on it rests the chief merit of this type of furnace.

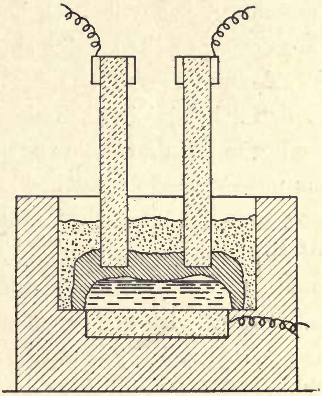


Fig. 9.—Three-Phase.

To-day, the battle chiefly rages between the advocates of Type 7 and Type 10. It is necessary, therefore, to find out if we can the merits and demerits of both systems. All four of the types mentioned have been tried by the author on a large scale. Classifying the four types into two systems (furnaces with, and furnaces without, a connected bottom electrode), the author is of the opinion that the first-

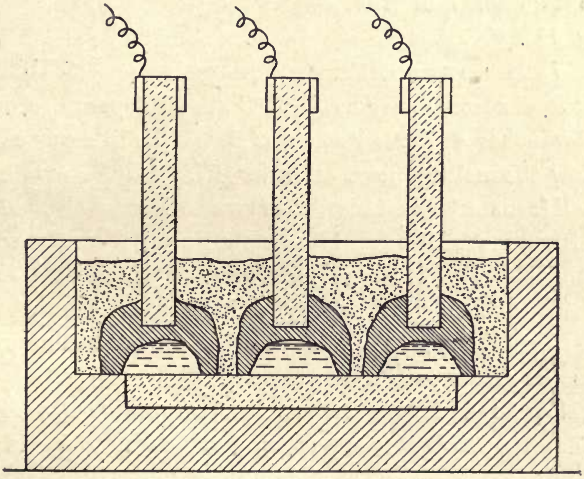


Fig. 10.—Three-Phase.

named type will, on the whole, give better results, but it requires better raw materials and betterservice, while the second-named will work better where the raw materials are poorer or the service slacker.

To understand the reason for this, the peculiarity which distinguishes the electric furnace from others must be borne in mind. The peculiarity is so important that the author is tempted to say that the beginning, middle and end of the electric furnace is the extremely small size of the high temperature zone—it may, perhaps, be clearer to the beginner if we say that the zone within which all the real work of the current is done, is confined, within probably a few inches, to the narrow path between the two ends of the electrodes (see Fig. 11).

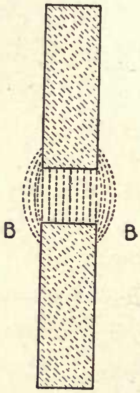


Fig. 11.

While the temperature at the ends of the electrodes may be 3,200°C., the temperature only a few inches away, say at point B, will be in many cases below the melting point of lime. This may be seen in a small furnace for instance, with two horizontal electrodes, no fused material being found a foot away from the path of the current. It should, however, be pointed out that as the quantity of energy passing into the hearth increases, the zone of fusion tends to spread farther outside the direct path of the current.

Now in a carbide furnace the impurities have the unpleasant habit of accumulating at the bottom and of solidifying there if the accumulation is allowed to get too deep. These impurities consist mainly of compounds of magnesium and silicon. They are conductors when sufficiently hot, but naturally they have a much lower electric conductivity than the molten carbide. If, therefore, the bottom carbon is allowed to have a layer of solidified matter accumulate above it, this layer will cause loss of current through its resistance, and although this resistance itself naturally causes Joulean heat, this latter is practically of little or no value, because it is too far away from the zone of high temperature.

Current is therefore wasted almost equal in amount to the resistance of this solidified layer of impurities. With a careful staff and good materials the impurities will not be allowed to accumulate, but where the materials are poor and the management slack, the constant rising of the tapping hole—and the decrease in production—will plainly show that solid matter is accumulating more and more at the bottom of the furnace, and consequently more and more current is being wasted.

The great merit of the furnaces shown in Figs. 8 and 10 is that however great may be the collection of impurities, there is very little loss through the resistance set up by these impurities, for the simple reason that, after the furnace has once got into full working, the molten bath of carbide and the incandescent raw material form the idle electrode of the furnace. It is, therefore, quite clear that as long as the molten bath is maintained, the loss through resistance in the furnace itself will be little more than is caused by the molten bath; in short, this arrangement of the furnace almost shunts the impurities out of the circuit.

This being so, it might well appear that the furnace with no connected bottom electrode is the only practical one, inasmuch as to a great extent it carries in itself a remedy for the slackness which is nearly always to be found at some time or other in a factory. But it has its disadvantages also, which chiefly are:—

(*a*) Lower production than that of furnaces of other type, and, of course, equal capacity.

(*b*) Higher consumption of electrode carbon and of raw materials.

(*c*) Higher cost for labour.

As regards point (*a*), it may be mentioned that there are at present furnaces of other construction in use, which, with a load of only 1,000 to 1,100 kilowatts, produce regularly at least 6½ kilos of carbide per kilowatt—24 hours, a figure which, we believe, no constructor of three-phase furnaces with three upper electrodes will guarantee.

Three reasons for the lower production may be mentioned. Firstly, in furnaces with more than one upper electrode, of the construction usually adopted, the current can find its way not only in the useful direction (*i.e.*, through the lower ends of the electrodes, where the carbide is formed), but also through the sides of the electrodes.

A second loss occurs through the large amount of current required for the electric "tapper" usually necessary to open up the tapping hole before the carbide is run off.

A third probable reason is that a three-phase furnace with three upper electrodes is in reality three distinct furnaces, for each electrode forms its own zone of fusion or pool, which is separated from the next pool by a poor conductor, *i.e.*, the mass of heated, but probably not liquid, material. In case the connection between the three hearths is formed by an idle bottom electrode, there is, of course, a loss through resistance, and, in addition, one of the great advantages of the three-phase furnace (viz., ability to work without appreciable loss in spite of accumulations of impurities at the bottom of the furnace) disappears.

Although the above-mentioned resistance naturally sets up a corresponding amount of heat, it is questionable whether a great part of this heat is not wasted: in other words, it may simply heat the solid matter between the zones of fusion, solid matter which is, in most cases, not melted at all.

As regards point (*b*), the chief reasons why the furnace with only upper electrodes has so much higher an electrode consumption than single-phase furnaces, is, firstly, that the position of the electrodes of the former type has to be constantly "regulated," and, in the writer's experience, the constant moving of the upper electrode invariably causes higher consumption.

Secondly, the higher voltage used also entails a higher consumption. It is, however, only fair to say that the constructors of three-phase furnaces have lately made notable advances in economising electrode consumption, and will now guarantee a figure of 20 kilos per 1,000 of carbide when coke is used. The figure is, however, nothing particularly brilliant.

The higher consumption of raw materials is probably due to the higher voltage at which the three-phase furnaces work. The higher the voltage, the less quietly the furnace will work and the more "blowing" and other disturbances there will be, with the resulting carrying away of particles of raw material.

As regards the higher cost for labour, the writer's experience is that it takes at least as many men to fill and tap a large three-phase furnace, with its three separate tapping holes, as three single-phase furnaces of the same capacity. Indeed, why should this not be the case? It has already been shown that a so-called three-phase furnace is in reality nothing but three separate furnaces in one and the same framework, so that there is, at any rate in works using about 5,000 e.h.p., just the same number of furnaces to fill with raw material. There is, moreover, the fact to be considered that the three-phase furnace uses more raw material—hence more labour.

The chief stumbling block (unless an automatic regulator is used) is, however, the man who sits on a stool for eight hours at a stretch regulating the electrodes. There are, of course, three of them for the 24 hours, and these three men represent an appreciable addition to the three shifts of three to five men each, or say 9 to 15 furnace hands in total, required to work the furnace room of a medium-sized factory.

The higher electrode consumption in the three-phase furnace also causes extra cost in another direction, for it is evident that more labour will have to be expended in the preparation of the carbons for the electrodes. As the life of an electrode depends in a very great measure upon the care expended in preparing and mounting the carbons, this extra item of cost cannot be ignored.

We mentioned previously that of late progress has been made as regards electrode consumption in three-phase furnaces. The chief advocates of this system seem, however, to think that the users of single-phase furnaces have remained stationary. Such is by no means the case.

It has been contended that most of the cost for labour for regulating the three-phase furnaces can be got over by the use of the automatic regulators referred to above, by means of which the voltage or amperage can be kept practically constant, such as, for instance, the Thury regulator.

It may, therefore, be well to mention that this method of raising or lowering the voltage is covered in most countries by what appears to be a strong patent.

It would, therefore, be well if the thick and thin partisans of large three-phase furnaces cleared up this question of the cost for labour by giving properly authenticated proofs. In recent publications they have acknowledged that their consumption of raw materials is greater and their production of carbide if anything less than in single-phase furnaces of 1,000 kw.

They claim that the advantages of their furnaces consist mainly of the reduced bill for labour and the lower capital outlay for buildings and plant.

As far as the reduced cost for labour is concerned, the writer's investigations all go to show that there is certainly no economy in the labour bill; on the contrary, the largest users of single-phase furnaces in Europe claim—and apparently correctly—that their cost for working their furnaces is less per ton of carbide than the cost of the largest factory in Europe using large three-phase furnaces.

If the factory is small, say of 3,000 h.p. or less, it is quite evident that the furnace shown in Fig. 7 will be more advantageous, for this power can, by means of the Scott connection, be put on two furnaces, so that the single-phase furnaces will have only two top electrodes as against three fo the three-phase furnace. It is true that there will be two bottom electrodes and we therefore have to ascertain whether a bottom connection is likely to cause more trouble than a top connection, or not.

In the author's opinion there can only be one answer to the question—the bottom holder, if properly constructed, will cause infinitely less trouble and expense than any type of top holder.

In proof of this assertion, the author will cite the fact that in the last six years, at the five different factories he is connected with, there has been only one case of a bottom holder giving trouble, and even in this instance the cause and the remedy were found to be very simple. On the other hand, every electro-thermic engineer knows that the most troublesome part of the electric furnace is the upper electrode. It has constantly to be changed (we have already seen) at least 80 to 100 times as often as the bottom electrode—and it has the additional enormous disadvantage of requiring a flexible connection, which can be rapidly connected and disconected. Hence the necessity for copper cables, which rapidly oxidise (the oxidation, indeed, sometimes taking the form of combustion), or of flexible busbars (which have their own peculiar evils), and the everlasting trouble of cleaning contacts every time an upper electrode has to be changed.

There are also other objections urged by the opponents of the large three-upper-electrode furnace. These objections are mainly of the "putting all your eggs in one basket" type. The author does not attach much importance to these objections.

As regards the claim that the three-phase furnace requires much smaller conductors than the single-phase, while, in addition, the latter will require the two bottom holders or connections, the writer would like to say that, after working out all the figures in the case of a factory he had to build, he came to the conclusion that the extra cost of the third upper electrode for the three-phase furnace, with its electric crane, connections, cables, two upper electrode holders (one in use and one spare), water cooling, etc., would be more than the extra cost for the heavier conductors and bottom holders for the two single-phase furnaces.

As regards the claim for economy in buildings, there is nothing in the argument; the contrary is the case, for it is quite clear that if the constructor of the single-phase furnaces cares to do so, he can place his two upper electrodes actually in less space than is required for the three of the three-phase furnaces, and he can, in addition, cover them in and recover the carbon monoxide at less expense, for it is clearly cheaper to cover in two top electrodes than to cover in three.

For powers up to 3,000 h.p. there is therefore not the slightest doubt in the author's mind that the advantage lies altogether—both as regards capital outlay and running expenses—with the single-phase furnace. When, however, we go a step further and take factories utilising more power than is equivalent to, say 1,300 kw. per furnace, and this power is in the shape of three-phase alternating current, there is little doubt that the capital outlay will be less if three-phase furnaces are installed.

But is the saving of a little capital the be-all and end-all of running a factory? Surely the most important matter to decide is what the cost of manufacture is going to be.

We will assume that the power available is 20,000 h.p., or say 15,000 kw., and that this power is to be utilised either in one so-called "double" three-phase furnace or in 12 single-phase furnaces.

We will assume the building for the latter costs £1,000 more than the former (although the writer does not know why it should), and that the extra cost for the conductors, etc,, is £400 per furnace, or £4,800 in total (again the writer does not know why the extra cost should be so much).

The extra capital outlay will be therefore £5,800, so that if we allow 20% per annum for depreciation, interest, etc., the extra running cost will be £1,160 per annum.

Let us assume, further, that this power produces 25,000 tons of carbide per annum.

The builders of these furnaces acknowledge that they use more raw material per ton of carbide, but they do not say how much.

Judging from the guarantees they offer, the consumption is at least 10% more, but we will take only 5% more.

	s.	*d.*
5% on 1 ton of lime at 15s. =		9
5% on 0·6 ton of coke at 25s. =		9
therefore per ton of carbide =	1	6

Or for 25,000 tons, £1,875.

The saving on the capital expenditure is, therefore, far more than wiped out by these two items alone, although they have been taken at a fairly moderate figure, for not many factories can get coke with only 7% of ash for £1 5s. per ton delivered at the works.

On the top of this comes the extra cost for electrodes, and probably for labour, and the lower production, so that promoters of new carbide factories will do well to ponder carefully over the matter.

The writer, however, wishes to repeat that the three-phase system is under certain conditions the best to adopt.

We now turn to the argument lately put forward in favour of the three-upper-electrode furnace that the possibility of building this furnace for very large capacities enables the furnace to be covered in, and thereby the CO to be collected and the bill for electrode-carbon to be reduced.

We have already pointed out that it is just as easy to collect this gas from single-phase furnaces as from any other. It may also be pointed out here that the idea of covering in the top of the furnaces and collecting the CO is not new. The idea forms one of the prominent features of the old furnaces of the German Gold and Silver Refinery, which were at one time used in a factory under the management of the writer—and had the highest electrode consumption known to him. Furnaces with covered-in electrodes figure by the dozen in the text-books and patent specifications.

In order to show how great minds think alike, we reproduce below a drawing taken from the latest patent of one of the most prominent advocates of the covered-in furnace (Fig. 12) and a drawing of the old furnace used about twelve years ago at Niagara Falls (Fig. 13). The arrangements for feeding in the raw material through the openings A, carrying away the carbon monoxide through the openings XX, and passing the electrode conductors through the roof seem to be identical in principle.

We will now deal with another type of three-phase furnace, viz., Fig 9.

This furnace was first used at the Cordoba factory, under the managing directorship of the writer, in 1907. Its use was abandoned, because certain technical difficulties caused it to show no particular advantage in any respect above the single-phase furnaces of smaller capacity.

Since it was pulled down experiments in another direction have shown that a simple method can probably be arrived at for regulating the voltage between the electrodes, balancing the phases and reducing the electrode consumption.

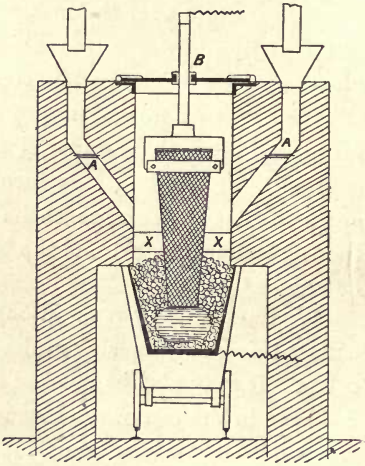


Fig. 12.

Should these anticipations be realised it is evident that this furnace would have decided advantages over the type with three upper electrodes, if only for the reason that the load per hearth could be considerably higher (without causing too unfavourable a power factor) than in the case of three-phase furnaces with three upper electrodes and three separate hearths, for, all other things being equal, it is a law of furnace practice that the heat losses decrease, per unit of energy used, as the total amount of energy per hearth increases.

Many attempts have been made to construct furnaces with no upper electrodes (an indirect testimonial to the solid merits of the bottom electrode), but hitherto with no great success. The stumbling-block is usually stated to be the difficulty of regulating the voltage or amperage, owing to the practical impossibility of continually moving horizontal, or nearly horizontal, electrodes which are embedded in a mass of raw material and usually of masonry.

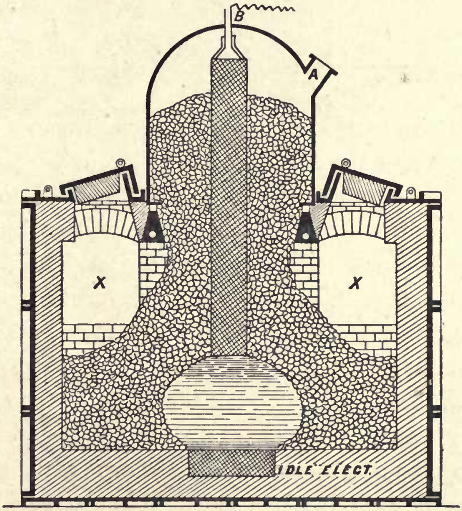


Fig. 13.

Experimental furnaces of this description usually take the form shown in Fig. 14, and the author may cite as an instance in point the furnaces at Trowbridge, Wilts., which were in use in 1897.

These furnaces, as the writer saw for himself, produced a block of carbide of excellent quality, the electrodes being drawn farther apart as the block was built up.

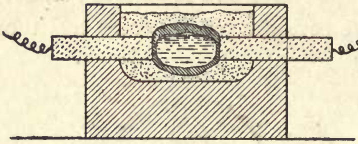


Fig. 14.

The molten carbide naturally sank at first to some little distance below the level of the electrodes. The results obtained were not unfavourable for that period of the industry, especially in electrode consumption, but directly tapping furnaces of fairly large capacity began to put their product on the market and over-production caused a heavy fall in prices, the fate of this furnace was sealed, for it could not be successfully tapped. Tapping could, however, have been made quite feasible by modifying the design somewhat.

This type of furnace has been the pet idea of nearly every carbide engineer, most of whom are still turning the matter over in their minds, and it is therefore not unlikely that one of the next steps in the eternal forward march of the industry will be the evolution of a furnace which has all its electrodes even more completely submerged than is the case in the furnace shown in Fig. 13.

Having described the chief types of tapping furnaces we will now turn to those producing ingot or semi-ingot carbide.

Of these, the only one cutting any particular figure is that used by the Union Carbide Company at Niagara Falls, but it must be acknowledged at once that this furnace is a particularly ingenious one and, if properly constructed, should theoretically have a larger production per unit of electricity than any existing tapping furnace.

Almost every good point which a furnace should have is found in this type. In the first place its production should certainly be higher, for it is a well-known fact that block or ingot carbide requires a lower temperature to produce than tapped carbide; hence a smaller consumption of electric energy per ton produced.

The next advantage is that the arrangement of the electrodes should allow them to be efficiently protected from the oxygen and other gases produced in the furnace; hence economy in electrode consumption.

Thirdly, the furnaces should be worked with a minimum of labour, for all the feeding can be done mechanically.

As is, however, the case with most good things, this furnace has certain drawbacks, which somewhat offset its good points. The chief of these drawbacks are that the carbide produced is of the ingot or "quick" description, and that the blocks of carbide have to be cleaned before crushing.

Before passing away from general considerations it will be necessary to touch upon the question of direct (continuous) current versus alternating current.

For a long time it was asserted that direct current must be disadvantageous, because it was supposed that in some way two actions were going on in the furnace—viz., an electro-thermic action producing carbide, and an electrolytic action which decomposed it again.

While it is undoubtedly certain, as the experiments of Grauer show, that carbide can be decomposed by passing a direct current through it, either this action does not go on concurrently with the electro-thermic one, or direct current has so much higher a production than alternating current that the electrolytic action is neutralised.

The author bases this opinion upon the fact that he was once able to carry out some tests with both types of current, in furnaces of practically identical capacity and using the same description of raw material. The difference in production was, if anything, in favour of the direct current.

CHAPTER VI.

CONSTRUCTION OF THE FURNACES. THE BODY.

We will now turn to the details of the furnace. As a rule, a carbide furnace consists nowadays simply of a steel case or box, or a steel frame, lined inside with suitable refractory material, and having a tapping hole very similar to the tapping hole of an iron furnace or cupola. In the larger furnaces a tendency has manifested itself to use the raw materials themselves as the inner lining for the furnace, which in such cases usually consists of an outside case or box of iron or steel, with a comparatively thin lining of refractory bricks and other suitable material. The furnace in this case is so dimensioned that the refractory lining is so far removed from the melting zone that it remains unattacked by the heat, as shown in Figs. 7 to 10. The space inside the masonry wall is, when the furnace is in operation, filled up with raw materials. The centre part of this raw material, *i.e.*, that between the electrodes, is, of course, rapidly converted into molten carbide, which again atracks the materials immediately surrounding it, but only to a comparatively short distance. As the distance from the path of the current grows greater and greater the heat action becomes less and less, until at a distance of one to three feet from the path of the current (dependent upon the load of the furnace) no conversion of raw material into carbide, or partly used material, will be found to be taking place.

This is undoubtedly the cheapest way of constructing a furnace. If properly proportioned the bricks of the fire-brick lining will be found, after, say, a year's run, to be quite suitable for lining the furnace again, and the repairs will therefore be limited, as far as the masonry is concerned, to the labour for rebuilding.

It is, however, very doubtful whether this practice is the more profitable. The author's experience is that if the masonry basin be built of the smallest possible size suitable for the power in question, for instance, so that the inner edge of the refractory lining just begins to melt, the production will be somewhat higher.

In order to settle this question two furnaces of equal capacity, standing side by side, were lined in the two different manners. A run of eight months showed the production to be:

With the lining of refractory material, 106.
With the lining of raw material, 100.

This small difference in the production more than paid for the loss of refractory material, but there was not much in it either way.

Arrangements are generally made in furnaces with a steel case, or steel frame, to break the magnetic circuit. Although the waste of current is not particularly great if this break be omitted, it is desirable to have it, if only for the reason that at the point where the busbars cross iron ties at right angles, these iron ties will be found to be red-hot, and it is often exceedingly unpleasant for the workmen to have red-hot metal at this particular point.

Another important point in connection with the furnaces proper is the arrangement enabling the men to work the furnace from the top. In most furnaces this is effected by carrying an iron platform—which should be insulated—round the top of the furnace, so arranged that parts of this platform can be utilised for storing small quantities of raw material. In the last factory constructed by the author, the construction of these platforms was entirely altered and a different material used.

CHAPTER VII.

THE BOTTOM ELECTRODE HOLDERS.

We now turn to the details of the other parts of the furnace. We will first consider the lower carbon-holder, as this, being built into the furnace, might well be considered a part of the body proper.

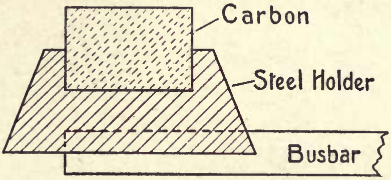


Fig. 15. Section of bottom holder.

In the majority of factories using furnaces with bottom electrodes the bottom holder simply consists of a pan or block of steel in which the carbons stand, this block or pan having busbars (conductors) of steel cast into it for the purpose of forming the connection to the copper busbars.

In holders of the type shown in above sketch, the right-hand of the busbars is usually bolted to the copper or aluminium busbars leading to the transformers.

This type, modified in a dozen different ways, was in use in most factories until quite lately, and, indeed, is still in use in some, but it has its disadvantages. In the first place, it is necessary to make the connection between the carbons and the iron holder in the most careful way or burning will ensue, and as carbon and iron or steel have different coefficients of expansion, this task is not easy.

Secondly, the holder must be kept cool, or the furnace may collapse through the holder melting, and thirdly, the presence of so large a mass of iron in the circuit undoubtedly, in the writer's experience, unfavourably affects the power factor (cos ø), although the text-books state that iron has no influence in this direction if heated to the temperature such a holder works at.

If the author's view be incorrect, it is difficult to understand how, with four different furnaces, in two different factories, the power factor was found to be greatly improved by the substitution of a copper bottom holder for the steel ones.

These considerations led the writer some years ago to eliminate the bottom holder altogether and make the connection in a new manner, the capital cost of which hardly exceeds that of a length of busbar of the same current capacity, and which has, moreover, the great advantage of carrying the metallic part of the circuit almost right up to the molten bath of carbide, thereby diminishing the loss through ohmic resistance. The results have been entirely satisfactory, for the production has increased almost exactly according to calculation, and the first connection of this description ran for more than four years without a penny's expenditure for renewals, and, indeed, without the masonry round it being disturbed. The author mentions this in order to show that one of the advantages claimed for three-upper-electrode furnaces, viz., that they can run for six months, or even a year, without repair, is, after all, nothing particularly brilliant.

Whatever the construction of the bottom holder may be, it is, of course, of paramount importance to prevent the carbons being attacked by air. If air can obtain access to a red-hot carbon, combustion will naturally ensue and the life of the carbon be short.

In furnaces with an idle bottom electrode, it naturally matters little whether the idle electrode burns out or not, when once the furnace is in full swing, because, as already stated, the molten carbide becomes the actual idle electrode immediately the bath has been formed.

Difficulties, however, arise when a sudden stoppage of a few days, for instance, through a breakdown in the power station, or the line, compels a furnace, having connected upper electrodes only, to be put out of operation. The restarting is usually difficult, for the bath of carbide naturally solidifies and ceases to be a good conductor. Certain little tricks can, however, usually be adopted for restarting, and in the worst case a new bridge of carbon can be laid at as low a level as possible in the furnace, in order to form the necessary connection between the three electrodes.

In all the older types of furnaces, with connected bottom electrode, water- or air-cooling has to be adopted. The amount of energy that the cooling represents is very considerable, but the author has good reason to believe that it does not represent a loss of useful energy. It is dealt with farther on. In the three-upper-electrode type of furnace this cooling at the bottom of the furnace is, of course, dispensed with, but in some cases its place has been taken by cooling of the exterior of the furnace itself.

Before leaving the bottom electrode, one type may be mentioned which was in favour some years ago, *i.e.*, the electrode of carbon which was carried right to the outside of the furnace, so that the part of the circuit between the molten bath and the busbars consisted entirely of carbon. It is scarcely necessary to point out that such an electrode represented a considerable waste of energy through the high ohmic loss of carbon as compared with that of iron or copper. Such furnaces were, however, usually constructed with a very thin back wall, so as to make the length of carbon as short as possible.

CHAPTER VIII.

THE UPPER ELECTRODE HOLDERS.

If the variety of systems in use for the bottom carbon holders has been small, the same cannot be said of the upper holders. It would probably be safe to say that every carbide factory in existence has used on the average at least four different types; there are more than 150 variations figuring in the literature of the British Patent Office alone.

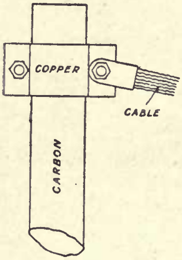


Fig 16.

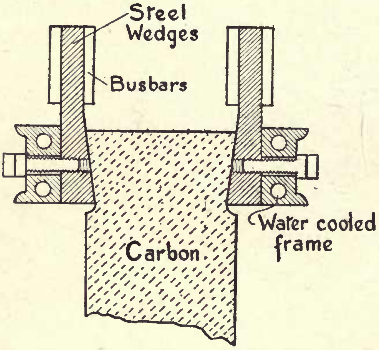


Fig 17.

In the beginning, when upper electrodes were small, the original Siemens type (Fig 16), consisting of a collar of copper or other metal encircling the electrode, answered all purposes. As soon, however, as it was found that an upper electrode consisting of only one carbon would not suffice to carry the current, other designs came into being. For a long time a favourite form was that known as the Swedish type (Fig. 17), another variety of which is shown in Fig. 19.

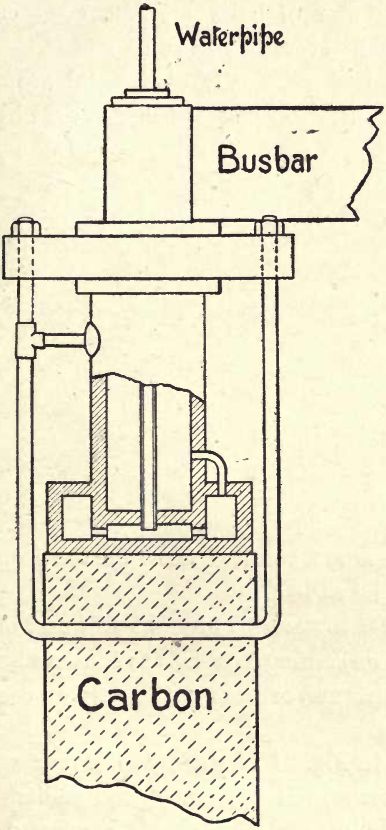


Fig 18.

From the illustration it will be seen that contact was made between the carbon and the leads by means of steel contact-plates, and that the heads of the carbons took the shape of an inverted truncated cone, so that the weight of the carbon might tend to make the contact tighter.

The great disadvantage of this type was that the iron contact plates had to be carefully fitted, and, in spite of all care, burning always took place, so that the plates had to be planed every time a fresh set of carbons was used.

One of the most successful types of upper holder is that known as the Italian (Fig. 18).

The chief advantage of this holder was that it was one of the first to be water-cooled. This water-cooling did away, to a very great extent, with all the worries of contact-plates burning and of bolts melting, such as formerly led to a stoppage every day or so.

This electrode consists practically of a metal head, which is placed against the top end of the electrode by means of a rod, a good contact being secured by means of a paste of carbon smeared between the iron holder and the top of the carbon.

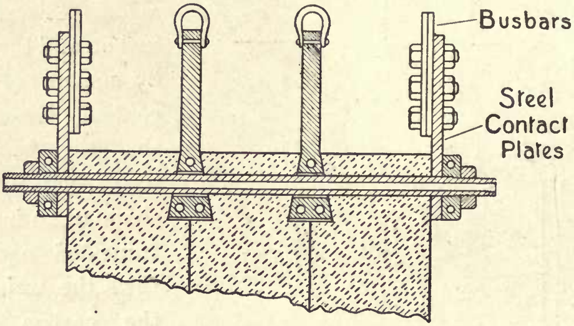


Fig. 19 (Swedish with Central Wedge).

It would lead too far to describe even a tenth part of the various holders, so we confine ourselves to illustrating below several types which are, or were until lately, in use at well-known factories.

The holder shown in Fig. 21 is greatly in favour at many Continental factories. It has many good points.

It consists roughly of a hollow steel, copper or aluminium casting, having two hollow jaws, which are wedge-shaped at the bottom so as to take the heads of the carbons, which are also wedge-shaped. The weight of the carbons, sometimes aided by screw-down bolts on the top, is supposed to cause good contact between the carbons and the holder, the contact being improved by the usual device of smearing carbon paste between the jaws of the holder and the wedge-shaped parts of the carbons. The water-cooling is extremely thorough, and the holder is easy to erect.

Its chief disadvantages are, firstly, that if burning should take place at any part, practically the whole of the holder is rendered useless if the burning has gone so deep that the jaws cannot be re-planed; and, secondly, that the heads of all the carbons must be of exactly the same size and shape, as otherwise the head will make contact in one place and not in another.

Not one of the above-mentioned holders fulfils, in the writer's opinion, all the requirements of a really good holder, viz:—

(*a*) Any parts liable to burning or wear must be of the cheapest description, and therefore must not require planing or milling, or other expensive machining;

(*b*) good contact must not depend upon the exact size or smoothness of the heads of the carbons, and consequently it should not be necessary to trim or machine the carbon heads;

(*c*) the assembling should be of the simplest description, so that a six-carbon electrode, for instance, should be assembled, bolted together, and the contacts made in half to one hour by one man;

(*d*) contact should be made in such a way that the expansion of the various parts has no practical influence on the efficiency of the contact, nor should a rise of temperature to say double the normal working temperature affect the contact ;

(*e*) the capital outlay should not be much more than the value by weight of the materials used.

It may be taken that, as a general rule, in spite of the exceedingly numerous experiments made with the object of finding a more durable material, carbon blocks, either of the ordinary compressed and baked type, or the graphite type made on the Acheson system, still hold their own generally as the most suitable material for the upper electrodes. For the bottom electrode it has, however, been found possible to substitute other materials, for instance, magnesite, in which iron bars or rods are embedded. These rods serve to carry the current from the zone of fusion to the bottom holder, until the mass of magnesite surrounding them has become sufficiently heated up to become a good conductor (Keller's Patent).

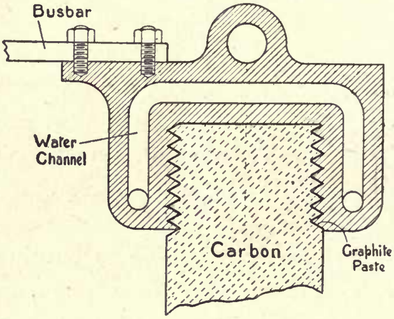


Fig. 20 (American).

This system cannot, of course, be so easily applied to the upper electrode, for the metal bar has an unfortunate tendency to melt and run out, leaving a portion of the magnesite block practically a non-conductor. Experiments, which look promising, are still, however, being carried out in this direction at the time of writing.

The current density to be given to the electrodes varies, of course, enormously, according to the system of furnace used and the material of which the electrodes are composed. The maximum density rarely exceeds 50

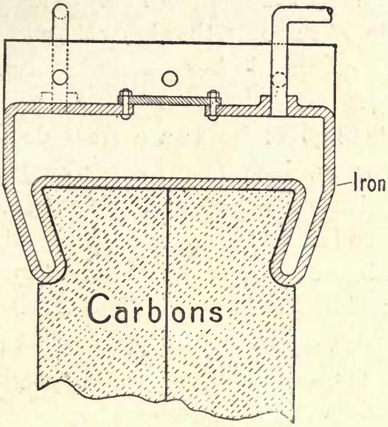


Fig. 21 (French).

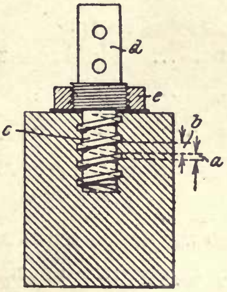


Fig. 22.

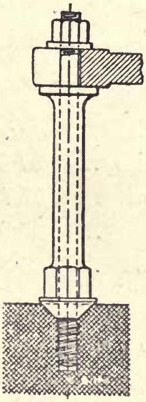


Fig. 23.

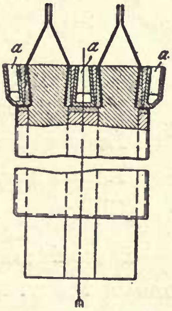


Fig. 24.

amps. per sq. inch (8 amperes per cm^2) or falls below 16 amps. per sq. inch ($2\frac{1}{2}$ amps. per cm^2). The higher the voltage, the smaller the electrodes may be for the amperes carried; or, in other words, the higher the current density. Some writers say that in low pressure furnaces, working with a voltage of say 35 volts between the electrodes, it is permissible to go as far as a current density of only about 6a. per sq. inch (say 1a. per cm^2), but in the writer's experience the results of attempting to spread the current over so large an area are distinctly discouraging.

Good carbon electrodes should have a specific resistance when cold of not more than about 0·005 ohm per cubic centimetre, equivalent to 50 ohms in a rod 1 metre long and 1 square millimetre in section, the standard often followed on the Continent.

The electrodes of artificial graphite made on the Acheson system have a far lower ohmic resistance than the ordinary baked carbons.

According to the *Electrochemical Journal* of April, 1908, the specific resistance of various electrodes is as follows:—

	Cold.	Hot.
Acheson graphite ...	37·4 ohms. ...	14·06 ohms.
Siemen's carbon ...	57·7 ,, ...	56·8 ,,
Lessing ,, ...	59·9 ,, ...	49·9 ,,
Retort graphite ...	46·1 ,, ...	47·5 ,,
Silicon	472·6 ,, ...	153·1 ,,

These figures do not entirely agree with tests made at one of the writer's factories, with a Silvertown special resistance set, nor is it altogether easy to understand why Siemen's carbons and graphite should deviate from the generally accepted rule that the resistance of carbon decreases as the temperature increases. In the "Electrical Engineer's Handbook" the resistance of graphite at 100°C. is given as approximately 5 per cent. *less* than at 0°C.

The tests carried out at the above factory by the author showed that the ohmic resistance of the particular type of carbon used decreased about 0·03 per cent. for each increase of 1°C. in temperature. These tests were, however, carried out at temperatures which, for electric furnace work, are comparatively low, and it is of course well known that as the temperature increases, the rate of decrease in the ohmic resistance becomes less. We, therefore, reproduce Hering's figures, published in *Metallurgical and Chemical Engineering* of May, 1910. Although these figures are intended to serve another purpose, they show how the decrease in the ohmic resistance diminishes as the temperature increases. For instance, the difference between 400° and 800° is, for carbon, 0·68; between 800° and 1200° it is 0·47; between 1200° and 1600° it is 0·38; and between 1600° and 2000° it is only 0·30.

	Carbon.	Watts per ampere for Graphite.
400°C.	1·00	0·85
600°C.	1·38	1·04
800°C.	1·68	1·19
1000°C.	1·93	1·32
1200°C.	2·15	1·43
1400°C.	2·36	1·52
1600°C.	2·53	1·62
1800°C.	2·68	1·71
2000°C.	2·83	1·79

In addition to the ohmic, or electrical, conductivity, it is of course clear that the question of the heat conductivity of the electrodes plays a very important part in the economy of a furnace, for unless the conductivity can be so proportioned that the Joulean heat set up by the electrical resistance is equal to the heat conductivity of the electrode (in other words, unless the ohmic resistance makes the electrode so hot that it prevents heat from being drawn out of the furnace through the electrode), it is clear that the electrode will conduct heat away out of of the furnace.

It is, therefore, necessary to know the thermal conductivity of the electrodes. It may, in the first place, be pointed out that, as a general rule, the thermal conductivity increases in about the same proportion as the electrical conductivity, and that, therefore, section for section, a graphite electrode will carry a much higher amperage per square inch into the furnace, and also, unless certain precautions be taken, remove more heat from it, than one of ordinary baked carbon.

The thermal conductivity of the carbon electrodes generally used by the writer can be taken to be approximately 0·4 calorie per hour per cube of one centimetre. The specific heat at 100°C. is 0·18 to 0·22.

PRE-HEATING RAW MATERIALS.

Before passing away from the furnace proper it may be well to make some mention of furnaces constructed to snare that will-o'-the-wisp, the pre-heating of the raw material. At some time or other nearly all young carbide engineers appear to be led astray by a deduction that as the raw materials can be more economically heated up to say 1200° C. by other means than in the electric furnace, for instance in a kiln heated by coal, it must necessarily follow that a considerable saving would be effected if the raw materials were first heated to as high a temperature as possible by these cheaper methods, and the electric energy simply used to give, as it were, the finishing touch to the process.

The most glaring example of this kind of reasoning is to be found in the case of the carbide factory at Niagara Falls, belonging to a Buffalo Company. At an expenditure sufficient to build three ordinary factories of the same capacity, a four-storey building of fortified concrete was built, and in the centre a massive high kiln or stack was placed, into which the raw material (limestone and anthracite small coal) was fed at the top. As probably anthracite was not found to burn the limestone very readily, natural gas, costing no less than 1s. 8d. per 1,000 ft. (say 0·75 Centime per cubic metre) was blown into the kiln.

After many—and very expensive—experiments had been made, the inventors (who, by the way, ought to have succeeded, for one was a Christian Scientist and the other a maker of harvesting machinery) did manage to burn their limestone and to run the mixture of lime and half-burnt anthracite into ingot electric furnaces, which produced a more or less irregular quality of carbide, at a most tremendous cost. After spending £60,000 in producing two or three hundred tons of carbide, the proprietors wisely decided to discontinue the manufacture.

It is so self-evident that practically any type of electric furnace pre-heats its raw material in the most efficient way (*i.e.*, by heat which would otherwise be wasted) that the only excuse that the author can make for dwelling on this point at such length is the hope that he may thereby prevent other experimenters from wasting their money in the endeavour to do a second time what the electric furnace does for itself.

CRANES FOR UPPER ELECTRODES.

The appliances for carrying and changing the electrodes consist nearly always either of vertical or horizontal cranes (runways). In the old times, the electrodes were usually suspended from a vertical crane of the ordinary type, which could swing round and drop its used electrode upon a trolley, which conveyed it over a tramway to the repair shop, the new electrode being taken up from another trolley.

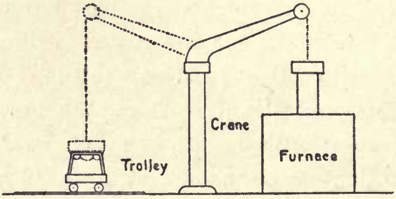


Fig. 25.

This system was subsequently greatly improved by arranging the cranes between each pair of furnaces in such a way that each crane could serve the furnace on either side of it. This rendered it possible to let the crane on one side of the furnace have the new electrode suspended at a suitable level, while the crane on the other side removed the old one. In this way the old electrode could be swung away by one crane while the other crane almost simultaneously swung the new one into place, and a considerable amount of time was gained in the changing of the electrodes. The disadvantages of this system are that the cranes are usually in the way of the platforms surrounding the furnaces, and they do not lend themselves very readily to the use of automatic arrangements for keeping the load on the furnaces steady.

The next step forward was the substitution of horizontal cranes for the vertical cranes. These usually consist of steel horizontal beams or joists, on which a carriage runs.

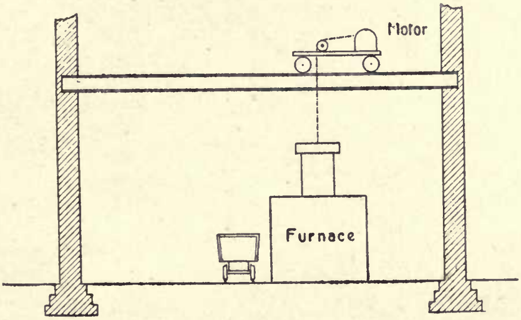


Fig. 26.

In the best types of these cranes a suitable motor (or motors) is provided on the trolley of the runway, which will give a vertical movement for raising or lowering the electrode, and a horizontal movement for traversing the load above the furnace. In the arrangement shown below, in Fig. 26, one workman can, by moving a switch, lift the used electrode well over the top of the furnace, and then, by bringing the horizontal movement into play, traverse the load to beyond the front of the furnace and then dump it upon the tram trolley standing ready. The tram trolley with the used electrode is then pushed out of the way, and the trolley with the new electrode pushed under the hook of the crane, which, by reversing the movements described above, brings the new electrode into position above the furnace.

This type of crane is now almost generally in use. It can, however, be immensely improved, so much so that half the time required for above operations can be saved.

CHAPTER IX.

CRUSHING APPARATUS.

Nothing like the care and attention are devoted as a rule to this part of the equipment of a factory that it should receive. The author has gone to the trouble of having a quantity of large carbide sent to a great number of makers of various types of crushing machines. In each case the large carbide was broken to a uniform mesh and all dust less than $\frac{1}{50}$ inch ($\frac{1}{2}$ mm.) screened out.

In some cases, certain types of crushers, which were widely advertised for their regular product and small loss in dust, actually wasted up to 8 per cent. more of the carbide in dust than other types.

It is clear that in times of cut-throat competition, such as have so often prevailed in the calcium carbide industry, a loss of 8 per cent. too much in dust would mean all the difference between paying one's way and the Bankruptcy Court, for although various methods have been introduced for utilising the dust (such as re-melting it in a special furnace), it is safe to say that each ton of dust represents a loss of about £4 to the manufacturer, unless he can make use of it for special purposes, such as the generation of acetylene for the dissolved acetylene process; the manufacture of other chemicals, such as tetrachloride of acetylene, cyanamide, etc. Even in the last-named cases, however, there is always considerable loss, owing to the gas-yield from the dust being usually only 50 to 60% of that from carbide of standard size.

The root of the evil, viz., unsuitable crushing plant, should be attacked, and it will pay as a rule to scrap inferior plant and replace it promptly by better appliances. In a factory producing hard tapped carbide, using crushers with the jaws set to produce a maximum size of 3¼ in., or 80 mm., the loss in dust should not exceed 4½%; indeed, on many occasions the author has seen it fall to as low a figure as 2¼%.

It is, however, impossible to obtain such satisfactory results if the carbide is soft, in consequence of its being manufactured by the ingot or equivalent process, or in case a larger quantity of granulated carbide (by which carbide of ¼-inch (say 7 mm.) mesh and smaller is usually meant) is required than the percentage obtained in the ordinary course of manufacture. Should the bulk of the carbide have to be converted into the granulated sizes, it will be found extremely difficult to keep the loss in dust down below 10%; in one case known to the writer, where practically the whole of the production was crushed down to ¼-inch mesh and below, the loss in dust amounted to 23 to 27%.

Happily, however, the day of the pernicious (from the carbide maker's point of view) acetylene generator, which dropped granulated carbide into water, has to a great extent passed away, so that to-day many of the European factories find some difficulty in disposing of the whole of their production of granulated carbide, instead of being obliged to crush lump carbide down specially in order to be able to supply larger quanties of granulated carbide.

In the earlier days of the industry, no carbide factory was satisfied, unless it was the possessor of a carbide crusher which broke up the carbide "along the lines of crystallisation." As the bulk of tapped carbide has no clearly defined "lines of crystallisation," but is on the contrary of a practically amorphous nature, this particular crusher had a somewhat difficult task to perform and it certainly performed it pretty badly, for it was a source of endless trouble and endless repairs.

To-day the stonebreaker type of crusher holds the field, but it will be well to point out here that there are stonebreakers—and stonebreakers. Many of the designs on the market suffer from the fault that they do not simply crush the carbide, but grind it as well, thus setting up an unnecessary amount of dust. The ideal machine would be one which simply cracked the carbide, much as a coal-pick breaks up a lump of coal with infinitely less loss in dust than if the lump be broken by a hammer.

Carbide as it comes from a stonebreaker has a flakey appearance, so that in many of the larger factories it is customary to pass the carbide through two crushers, in order to make the smaller sizes of squarer appearance than would otherwise be the case. What, however, is gained in appearance is usually more than lost in extra dust. Where such an arrangement is adopted, the sizes from 1 to 3¼ inches are usually obtained by means of a stonebreaker. The pieces of 1 inch and below are then passed by means of a conveyor (which should, of course, be as air-tight as possible) into a disintegrator or suitable crusher, which is set to produce the maximum mesh required.

As regards the crushers for the raw materials, since it has become customary to break up the raw material into pieces varying from the size of a walnut to that of the fist, avoiding the formation of dust as much as possible, the stonebreaker has had it all its own way.

Here also every care should be taken to secure a crusher which cracks rather than grinds, for an excessive amount of dust in the raw material not only means waste of the material itself, but trouble in the furnaces.

CHAPTER X.

SCREENERS FOR CARBIDE.

Owing to the rapid decomposition of carbide when in contact with the atmosphere, considerable trouble has been experienced in most factories in removing all the dust, and it is certainly safe to say that carbide "free from dust" exists to-day only in the imagination of the gentlemen who write the legends appearing on the decorated tins used for packing cycle and automobile carbide.

While the percentage of dust will be found to be very small in the lump sizes of carbide (one inch and above), it rapidly increases in the ¼-inch (7 mm.) size and below, so that no ordinary screener will be found capable of delivering these small sizes without perceptible quantities of dust. Various remedies for this are employed. In some factories, the ¼-inch and smaller sizes pass through a second screener, or a winnowing-machine somewhat similar to the winnower used for corn. The author has found a suction fan to be the most efficient way of removing dust, but the large quantity of air sucked through the carbide in this manner naturally means an increase in the quantity of dust, as the moisture contained in this air naturally attacks the carbide. The use of dry nitrogen of course obviates this evil to a great extent. Very many attempts have been made to design special screening appliances for carbide. For some time, when the quantity screened was very small and the price for carbide very high, good results were obtained by the use of shaking screens, which consisted of rectangular sieves set one above the other and kept in constant shaking movement by eccentrics or similar appliances. These shakers removed the dust very efficiently, but they had constantly to be cleaned out, as the flakey pieces of carbide insisted on jamming in the meshes of the screens. When, however, prices fell to a very low level and the quantities to be dealt with began to run into thousands of tons, the cylindrical screener rapidly asserted its supremacy and is now in practically universal use.

Here, however, there is also a great difference between a good screener and a poor one. The ordinary type of screener, such as is used for road-metal, will not give the best results with carbide.

CHAPTER XI.

TRANSPORT APPLIANCES.

In almost all of the older factories—and, indeed, in a good many of the modern ones—a great mass of tramways will be found encumbering the roadways and causing infinite trouble to the workmen. Such tramways are used mainly for the carriage of the raw materials from ship or railway truck or road vehicle to the stores or silos, and from the silos or stores to the lime kiln or crushers or furnaces, and secondly for conveying the carbide to the cooling floor or crushers and to and from the carbide store.

For the conveyance of raw materials, surface trams or railroads are often a very suitable system; for the conveyance of carbide—and hot carbide in particular—they often become an unmitigated nuisance. As a rule, they are for this purpose carried right up to the tapping points of the furnaces, with the result that they often become deformed by the heat, or work loose. A still greater objection to their use is the constant trouble caused by the liability of the cars to become damaged, not only by the heat to which they are often exposed, but by the rough treatment which they necessarily undergo.

The author believes that for the raw materials, gravity transport should, whenever possible, be adopted. It is the least costly system to instal and to work, and damages the raw material probably less than any other system. Probably its only disadvantage is that it has a tendency to separate the coke (or coal) from the lime in cases where the materials have been mechanically mixed. It is, however not difficult to arrange the gravity feed in such a manner that separation is for all practical purposes avoided.

For the carriage of the raw carbide and of the electrodes nothing gives so much satisfaction as overhead cranes or runways. Care must, however, be taken to provide overhead gear of a nature which will not be unduly interfered with by the enormous amount of dust usually present in the furnace and packing rooms of a carbide factory, dust which will accumulate to a depth of several inches or more in a few months and which creates anything but a satisfactory atmosphere for the electric motors, or even hand motors, used on cranes or runways.

With overhead cranes or runways, the working floor of the factory can be kept perfectly unencumbered and the repair bill, that bugbear of the earliest years of the industry, be reduced to a reasonable figure.

CHAPTER XII.

LABORATORY.

For the daily working of a carbide factory, the appliances required can be of a very simple description. The chief points to be taken care of are the testing of the raw materials for magnesia, phosphorus and silica—sulphur, as will be seen later on, playing a very subordinate role—and the testing of the carbide for gas-yield and purity.

For all these purposes a laboratory will suffice containing :—

1. A moderately priced chemists' balance and weights;
2. Bunsen burner, sand-bath, couple of platinum crucibles, porcelain saucers.
3. Chemicals.

This is of course the minimum outfit. For the testing of the gasyield, a generator is usually employed, which drops about ¼ lb. (say 100 grammes) of crushed carbide into an excess of water.

There are various apparatus for testing carbide on the market, descriptions of which will be found in most of the text-books on acetylene.

When testing carbide, the sample is first of all broken up by hand in an iron mortar to a mesh of about ⅜ inch (8 mm.) shovelled by means of a small scoop into a hand screen and screened out as rapidly as possible and then ¼ lb. weighed out accurately by means of a chemists' scale (which must be kept carefully clean and tested from time to time). The carbide is then placed in the generator (care being taken not to touch it with the hands or allow it to remain too long in contact with the atmosphere), the air-tight lid screwed down and the carbide gradually fed into the water, the gas passing first through a water-scrubber and then into the measuring bell. When all generation has ceased, the measuring bell should be carefully adjusted until a water-level shows that atmospheric pressure has been reached. A properly calibrated barometer and thermometer (both of which will require testing periodically) must be provided, in order to correct the gas-yield obtained.

For quick working not less than two testing generators should be provided.

The total cost of all the laboratory appliances mentioned above, including two gas-testing generators, need not exceed £60 to £70 and such a simple laboratory will suffice for all the work necessary for the commercial running of a carbide factory. Where, however, a large factory has the foresight to employ a chemist to work out problems connected with the development of the manufacture or applications of calcium carbide, it is clear that a greatly extended laboratory will be required.

As regards the testing of the quality of the gas from the carbide, little attention need be devoted to this, provided the manufacturer sees that the quality of his raw materials complies with the demands set out later on. In spite, however, of every care, occasional batches of inferior raw material will occasionally find their way into the furnace, due chiefly to the presence of pockets of phosphoric matter in the coal, as described under the heading "Materials of Manufacture," and the carbide engineer will do well to watch his carbide narrowly in order to prevent, as much as possible, carbide from such material passing into the packing room. The writer's favourite plan for keeping a constant watch on the presence of too much phosphorus is to burn all the gas from the testing generators in a small room or office in the factory. An excess of phosphorus will, if very excessive, be readily detected in the flame, while even a moderate excess will soon become apparent by the appearance of the well-known haze. If the burning of the gas in a number of burners in a small room causes no unpleasant effect, little fear of complaints from customers need be experienced.

Where it is desired to test for phosphorus in a more accurate manner, for instance, when complaints are made that the figure of phosphorus exceeds the maximum allowed by the Acetylene Association, recourse can be had to the ingenious apparatus invented by Mr. Gatehouse, the chemist to the British Acetylene Association This apparatus was first described in a paper read by Mr. Gatehouse at the Fifth International Congress for Carbide and Acetylene, held in London in 1909, and has since been adopted not only by the authorities in England, such as the British Admiralty, but in many Continental countries as well.

It will be seen from the illustration (Fig. 27) that the acetylene (from a determined weight of carbide) is burnt under a gasbell. The products of combustion are partly absorbed by water and partly collected on the interior of the bell and the quantities of silicic acid, phosphine, and sulphuric acid are ascertained by well-known means.

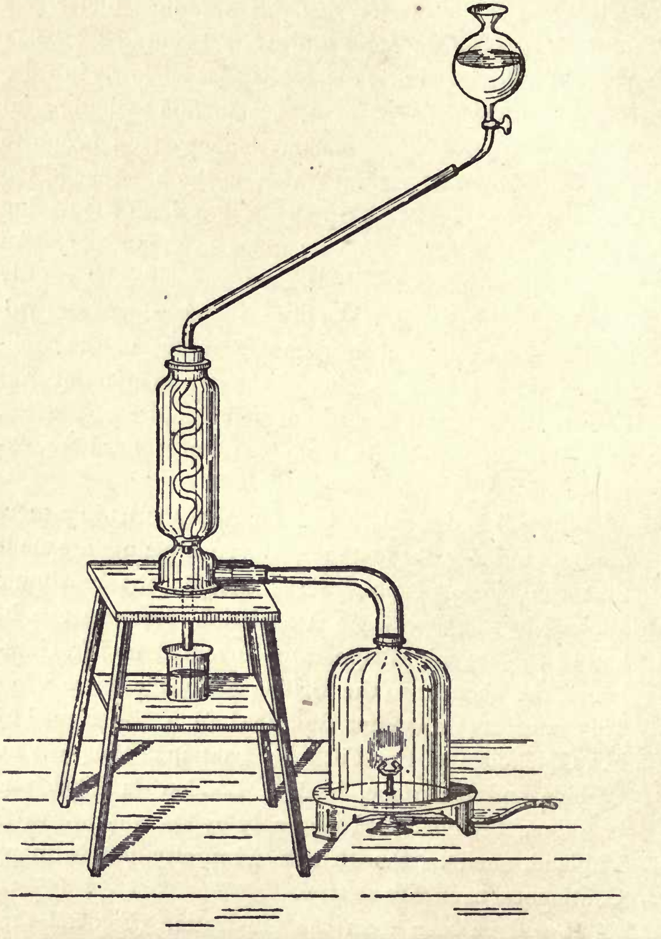


Fig. 27.

A more difficult matter is the provision of a simple apparatus for continuous use in a factory, by means of which it is possible to detect in a quick manner the presence of an excess of impurities likely to cause overheating in the acetylene generator. This is, however, an enemy to be carefully guarded against, for it can easily occur that, although the daily tests show no undue percentage of these impurities in the raw material taken in bulk, an excess may pass into the furnaces in the shape of pockets or veins which have escaped detection. A remedy for this practised at one factory is to pay the men at the limekiln a premium for throwing out any pieces of stone or coal containing an undue quantity of veins of slate, quartz, etc., but this is a very crude method.

Lately it has become necessary to provide means for testing the carbide for quick generation; in other words, to ascertain hour by hour whether the carbide is of such a nature as to cause overheating in any general type of acetylene generator. What appears to be a simple and cheap apparatus is in use by the writer for this purpose. A description of the first form this apparatus took has already appeared in the report in the "ACETYLENE JOURNAL" of the Annual Meeting (1914) of the British Acetylene Association.

CHAPTER XIII.

DRUM-MAKING PLANT.

Compared with the American type of drum, those supplied by most European factories must be considered rather inconvenient for the customer. The American maker has, however, had the advantage of a patent for carbide affording more or less a monopoly, and the high price of his carbide has enabled him to give his customer a more convenient type of drum.

The American type of drum has usually a corrugated body, as shown in Fig. 28. Occasionally the corrugated portions alternate with flat portions. The top is provided with a screw opening, so that a portion of the carbide can be removed and the lid replaced, enabling each drum to be used as a storage drum and obviating the objectionable necessity of transferring the carbide from the factory drum to a storage bin.

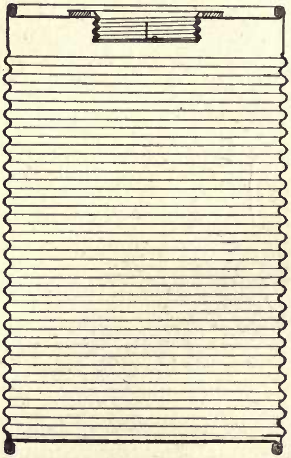


Fig. 28.

The American drum (Fig. 28) is usually made of thinner metal than is customary on this side and black plate is employed, the drum afterwards being coated with black varnish.

In Europe, on the other hand, the drum usually consists of an uncorrugated body, with a hole in the top, over which hole a disc of sheet metal is soldered. (Fig. 29.) The drums are made with straight sides, in order to obtain lower freights, in cases where the freight is charged according to cubic measurements.

In order to open this drum, the top must be cut open with a cold chisel, or the plate closing the hole unsoldered. The latter course is now not often followed, several accidents having been caused by a red-hot soldering iron (or even a black soldering iron, for a mixture of acetylene and air ignites at a lower temperature than that of a dull red soldering iron) having caused the mixture of gas and air always present in a drum of carbide—although not always explosive—to ignite.

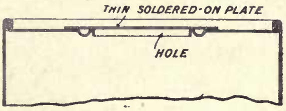


Fig. 29.

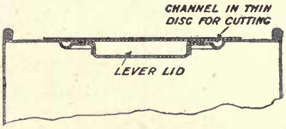


Fig. 30.

In order to enable the drum to be used as a storage drum in the American fashion, the writer some years back patented a pattern having a lever lid top, over which a disc of very thin tin plate was soldered, which could be removed by cutting with an ordinary pocket knife leaving the lever lid exposed. (Fig. 30.)

This method of closing the drum gave complete satisfaction to the customers, and it is largely used.

The foregoing details are given because it is clear that the plant for making the drums will vary somewhat according to the type of drum produced.

In European factories the plant for drum-making usually consists of :—

(*a*) Guillotine shears for trimming the plate to size ;

(*b*) Rolls for making the cylindrical body (these rolls can also be arranged to corrugate the body) ;

(*c*) Folding machine for making the vertical seam ;

(*d*) Closing machine for closing the vertical seam ;

(*e*) Machine for turning over the edges of the cylindrical body ;

(*f*) Machine for double-seaming the tops and bottom on to the cylindrical body ;

(*g*) Press or circular shearing machine for making the circular discs for the tops and bottoms ;

(*h*) Fly press (usually friction driven) for stamping out the top and bottom into shape, stamping out hole in top, and for making the disc for closing the hole in top ;

(*i*) Soldering stove, soldering irons, etc.

In most factories it is customary to make the vertical seam single folded.

The machines mentioned under (*g*) and (*h*), although usually employed, the writer considers old-fashioned. A good toggle-joint press will do the work of both, at a considerably lower expense for labour. It requires, however, a large carbide factory to keep heavy modern toggle-joint presses fully employed.

CHAPTER XIV.

LIMEKILN.

Three types of kiln are used for calcining limestone for carbide making :—

1. The old-fashioned type of contact kiln (Fig. 31), in which the stone and coal are in contact with each other and are fed into the kiln from the top in alternate layers ;
2. The modern type of contact kiln (Fig. 32), in which the coal and stone also come in contact with each other, but the coal is fed into the kiln through separate openings lower down, in order to avoid the waste of fuel occurring in type 1.
3. The gas-fired type, in which the coal does not come in contact with the stone, but is gasified in a producer or fire-box adjoining the kiln proper (Fig. 32), the producer gas itself being burnt in the kiln.

The cost of the limestone and its physical characteristics will in most cases determine the type of kiln to be used. It is certainly highly important that the lime should be as pure as possible, but the contact type will furnish almost as pure a lime as the gas-fired type, provided the lumps be picked out and the smalls and dust (which contain all the ash from the fuel) be discarded.

As the contact type kiln of modern construction will undoubtedly consume less fuel per ton of stone than gas-fired one, the former type has usually been employed where the limestone is cheap. Where the stone has to be imported from other countries, or transported a long distance, it is clear that the manufacturer cannot afford to waste a large proportion of his stone through discarding the smalls and dust and he will adopt the gas-fired type, especially if his stone should tend to deciepitate *i.e.*, break up during the burning, as is often the case with crystalline limestones.

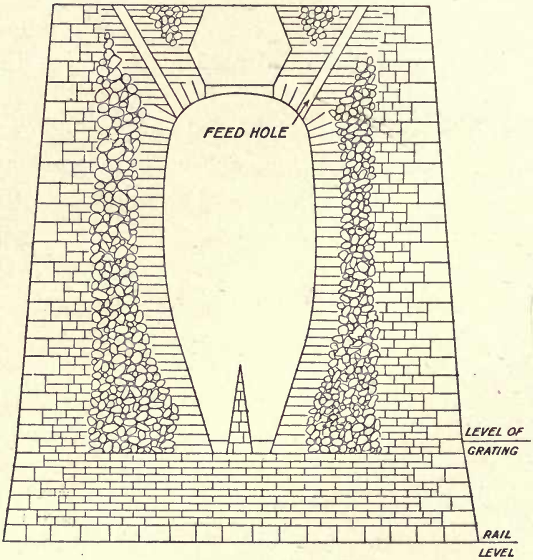


Fig. 31.

Many carbide manufacturers are, however, of opinion that the gas-fired kiln deserves under all circumstances the preference, because the lime it produces is more thoroughly burnt and there is consequently an absence of lumps with cores of uncalcined stone, which are passed through the kiln again by careful managers.

There is one important point which should not be overlooked when deciding upon the type of kiln to be adopted, viz., the question of repairs. Unfortunately in the race to obtain record figures for fuel consumption, some kiln designers appear to have overlooked the fact that kilns require repairing occasionally. One kiln tested by the writer depended for its efficiency (according to the patent) on a special interior arrangement, a part of which seemed remarkably well designed for the advantage

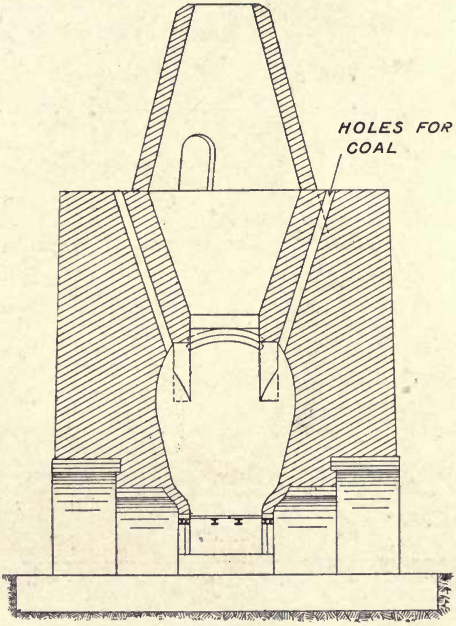


Fig. 32.

of the fire-brick industry, for it burnt away with great rapidity. This kiln saved about £25 per year in fuel consumption and it apparently cost about £50 per year more in repairs than any other form of modern kiln.

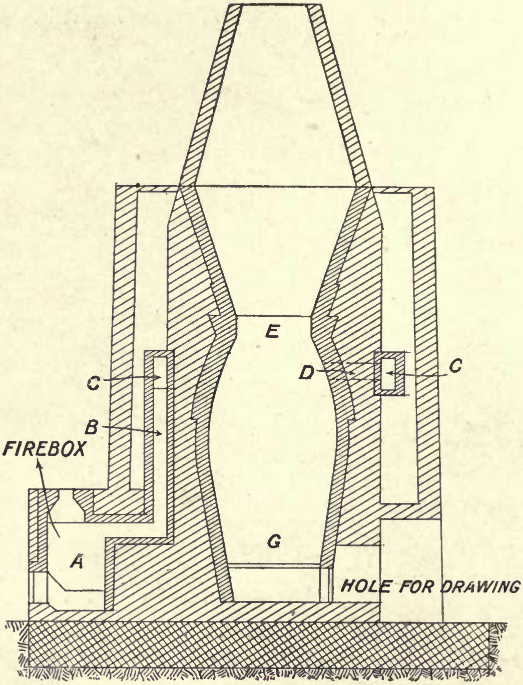


Fig. 33.

Summing up, therefore, it is clear that the type of kiln should be selected which best suits the individual case. In any case, however, that useful instrument, the CO recorder, should not be forgotten, for it will soon save its cost, especially in those countries where workmen are slack, which countries, strange to say, are often those where coal is scarce and dear.

As regards the cost for building a kiln, the following is the actual quotation of one of the best-known firms in the world, for a kiln to produce 20 tons of lime per 24 hours.

Materials :—

90 tons of firebricks.
11·6 tons of fireclay.
248,300 building bricks, 9 inches long.
16·7 tons of lime.
122 barrels of cement.
134 cubic metres (4,730 cubic feet) of sand.
116 cubic metres (4,100 cubic feet) of flint.
59 cubic metres (2,180 cu. ft.) of clay mortar.
147 cubic metres (5,200 cubic feet) of sand.
4 iron doors.
8 "hats."
4 iron plates.
3 reinforcing plates.
7 iron bands.
18 fire bars.
6 old rails. Total cost £820 11 0

Labour :—

128·6 cubic metres (4,550 cubic feet) of excavations	2	11	0
Laying 90 tons of firebricks	41	13	0
Laying 248,300 ordinary bricks ...	179	6	0
Laying 128·6 cu. metres (4,550 cu. ft.) of concrete	22	17	0
Erection of iron-work	2	18	0
Scaffolding	11	3	0
Total cost	£1,080	19	0

CHAPTER XV.

MATERIALS OF MANUFACTURE.

The materials used in the manufacture of carbide of calcium are primarily :—

(*a*) Carbon for the charge, in the form of charcoal, coal, or coke.

(*b*) Carbon for the electrodes.

(*c*) Lime.

CARBON FOR THE CHARGE.

Charcoal.—The use of this form of carbon for the manufacture of calcium carbide has practically died out, partly on account of the increasing difficulty of obtaining a sufficient supply at a low enough price, partly because its use has not shown those economical advantages which were anticipated from it.

The reasons for the latter objection lie near the surface. In the first place charcoal usually only contains about 56% of fixed carbon (with 28% of volatile carbon and 14% of H and O), and as it is extremely light and brittle, a very large proportion is lost in the shape of dust, so that it is safe to say that, for every 1,000 kg. of charcoal paid for, as a rule not more than 500 kg. enter into the furnace charge in a useable condition.

Although many others are of the contrary opinion, the writer has found the use of charcoal is undoubtedly accompanied by a higher consumption of electrode carbon. Against this may, however, be set the fact that charcoal enables a somewhat higher output to be reached than with anthracite coal or foundry coke, and the carbide obtained is of the highest possible quality.

Under the heading, "Results of Manufacture," some figures will be found giving the figures obtained when using charcoal, either alone or mixed with mineral coal or coke.

It is hardly necessary to state that where charcoal is used, it should be as hard and dense as possible. Charcoal from soft woods will give the poorest results.

COAL (MINERAL).

Only one form of coal, anthracite, has up to the present given anything like satisfactory results.

In the beginning of the industry, coke—either gas-, or foundry- or blast-furnace—was almost universally used, but as it became abundantly evident that the anthracite from South Wales is higher in fixed carbon and very much lower in ash than most of the cokes, and as, furthermore, it costs less for freight, owing to its higher specific weight, and, last but not least, is far less hygroscopic than coke (an important advantage in the moist districts where carbide factories are often situated), anthracite commenced to displace coke to a very large extent.

As stated above, the South Wales district is the source from which practically all the anthracite used in European carbide factories is drawn, and it may therefore be useful to point out that in that district the anthracite coals are divided roughly into two classes, viz., "upper" and "lower" measures. The latter are by far the purer and more expensive. They are usually much lower in phosphorus, that bugbear of the carbide maker, although the author will frankly state his experience shows that all South Wales anthracites are liable to contain pockets of phosphoric matter which are extremely difficult to detect, and that even the good collieries contain seams which produce coal totally unsuitable for making good carbide for lighting and welding purposes.

Opinions seem to differ as to whether it is more advantageous to use the higher or lower priced coal, but the author's own experience is that the higher price is more than offset by the higher production and the better quality of carbide obtained with the dearer coal.

It may be well to state here that the printed analyses generally sent out by the collieries are usually valueless. They are made on selected lumps of coal, and the author has never yet found a coal which went as low in ash as the analysis sent out by the colliery. Under these circumstances, it need scarcely be said that the collieries will never guarantee that their coal will comply with their own printed analyses; indeed, it is very difficult, even when the anthracite trade is bad, to get the better collieries to guarantee a maximum ash figure of 4%, even though their printed analyses show 1 or 1¼%.

The buyer of anthracite for carbide making will therefore do well to ascertain before shipment that the coal sent down to the shipping port complies with his requirements. Otherwise he will be quite liable to find himself with a cargo of coal which will produce inferior carbide, while no redress can be obtained from the suppliers.

Where a reasonably good limestone is used (containing, say, not less than 97% of carbonate of lime and not more than 1% of silica, not more than ½% of magnesia, and not more than 0·01% of phosphorus), an anthracite coal containing not more than 4% of ash and not more than 0·040% of phosphorus will give excellent results in a modern furnace. Of course, coal with a still higher percentage of ash can be used, provided certain precautions be taken, but trouble will inevitably arise and the production and quality suffer, directly the figure of the ash in anthracite begins to run much above 5%.

In this place the author would like to mention that the frequently propounded opinion that an inferior coal or coke can be made good by a specially fine limestone and *vice versa*, or in other words that it is only the total quantity of silica, total magnesia, etc., in both lime and coal (or coke) together which has to be considered, is, in his experience, totally erroneous. Such a theory does not, for instance, take any account of the different physical conditions of various forms of raw material.

For instance, hard coke, containing 7½% of ash, will work with perfect ease with a lime containing 1½% of silica, but if an anthracite containing 7½% of ash be substituted for the coke, trouble will arise.

The following analyses of some of the better-known anthracite coals of South Wales will give some idea of their general composition. It may be remarked here that the cleanest anthracite coal is always the lumps. The percentage of stone in anthracite has a tendency to increase as the size of the lump decreases, and a suitable quality in the lumps will contain far too much ash if the screenings, generally known as "culm," be taken. This culm will often contain 17 to 23% of ash, and no manufacturer of carbide for lighting purposes should allow himself to be persuaded to use this culm, even if mixed with large coal.

The following analyses are fair ones, *i.e.*, not taken from selected pieces.

	Fixed Carbon.	Volatile.	Ash	Sulphur.	Phosphorus.	Moisture & Loss.
Lower Measure Coals						
No. 1. Large Coal	**87·85**	**5·65**	**2·96**	**2·05**	**0·065**	**1·5**
No. 2. Large Coal	**92·87**	**5·70**	**1·43**	**0·78**	**0·03**	
„ Peas ...	**87·16**	**5·93**	**5·01**	**0·85**	**0·04**	**1·9**
No. 3. Beans ...	**89·88**	**5·51**	**1·96**	**0·84**	**0·012**	**2·65**
„ Peas ...	**91·02**	**5·60**	**2·95**	**0·84**		
No. 4. Peas ...	**89·2**	**6·2**	**2·95**	**0·81**	**0·11**	
Red Vein.						
No. 5	**87·76**	**7·15**	**2·24**	**0·82**		

Ireland also produces anthracite of the very first quality, as the following analyses will show:—

	Fixed Carbon.	Volatile.	Ash.	Sulphur.	Phosphorus.	Moisture and Undetermined.
Woolfhill ...	**90·08**	**5·15**	**3·64**	**1·00**	**0·032**	**0·90**
Skehana ...	**89·48**	**4·64**	**2·90**	**0·58**	**0·018**	**2·40**

As regards sulphur, it was generally believed that a higher or lower figure in the coal or coke was of little influence on the quality of the carbide, as sulphur is readily burnt in the high temperature of the electric furnace. The following figures for various samples of coal and the carbide made therefrom appear to show that

½% of sulphur more or less in the coal or coke makes little or no difference in the quantity of sulphur in the carbide :—

	Sulphur in the Coal or Coke.	H_2S in the Acetylene.
Sample No. 1	**2·1 %**	**0·19**
„ „ 2	**1·7 %**	**0·17**
„ „ 3	**1·72%**	**0·18**
„ „ 4	**0·82%**	**0·14**

These figures are better than those obtained by Prof. V. Lewes, but this is probably due to the carbide having been made in a different type of furnace, and having been "cooked" longer.

A whole series of complaints received lately about a certain make of carbide led the writer to have exhaustive investigations made, and he is now strongly of opinion that as a general rule far too little attention is paid to the question of sulphur in the coal or coke, and especially to the form in which this sulphur occurs.

Investigations show that if the sulphur is present in the shape of certain compounds, and the quantity of these compounds exceeds a given figure, large quantities of sulphur compounds will be contained in the carbide, which are volatile at comparatively low temperatures.

In the case of acetylene generators working with the minimum quantity of water, these compounds pass into the acetylene, instead of remaining in the water or sludge, and are burnt at the gas burners, thereby forming compounds at the jets, tending to stop the latter up.

Such sulphur compounds can be removed to a great extent, or almost entirely, by a good purifier. The writer's experience, however, is that not one private user of acetylene in ten keeps his purifier in a really efficient condition, and it is therefore a question whether it would not be wiser to use a more expensive raw material and charge a higher price for the carbide.

The following typical analyses show the composition of the ash of South Wales anthracite coals :—

Sample.	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Phosphorus.	Undetermined and Loss.
No. 1	50·4	28·8	12·3	1·8	3·4	0·57	2·73
No. 2	51·1	25·3	11·6	2·7	4·1	0·62	4·58

None of the impurities contained in the ash of a first-class anthracite — except, perhaps, phosphorus, with which impurity we deal separately farther on—is present in sufficient quantity to cause any trouble, if the necessary precautions be taken in the working of the furnaces and in the choice of the chief raw material, limestone.

The phosphorus is the enemy which we have always with us if anthracite be used. Some writers state that anthracite with more than at most 0·01 to 0·02% of phosphorus should not be used for carbide manufacture. The author, on the other hand, ventures to assert that such a coal cannot in the long run be relied upon from any of the South Wales collieries. Having access to the thousands of analyses collected by probably the largest handlers of anthracite in South Wales, he believes that the figure of phosphorus in even the best collieries in South Wales more often exceeds 0·02% than is below that figure, and he further believes that an anthracite with up to double the above figure will give a perfectly satisfactory carbide, if used in combination with a good limestone.

After all, the figure of phosphine allowed by the British Acetylene Association's Rules is 0·05% by volume, in acetylene generated by dropping small pieces of carbide into an excess of water and that this figure of the British Acetylene Association is well within the figure of safety has been repeatedly shown by allowing acetylene containing this figure of phosphine to be burnt in a small room in a large number of burners. No detectable haze was remarked.

The question therefore is whether 0·04% of phosphorus in the coal and, say, 0·01% in the lime will give a carbide yielding less than 0·05% by volume of phosphine in the carbide.

Many tests have been made to ascertain this, but the matter is not easy, for it is extremely difficult to obtain raw materials having approximately the figures of impurities desired. The following figures will, however, be of some use.

	Ph in the Coal (by weight).	PH_3 in the Acetylene (by Volume).
Sample No. 1	**0·04**	**0·028**
,, ,, 2	**0·032**	**0·024**

The writer wishes, however, to state clearly that these figures, and those for sulphur mentioned on page 83 were not obtained by grinding up small samples of the raw materials in the laboratory and then converting them into carbide in the laboratory furnace; such a process the writer considers useless for manufacturing purposes. The results were obtained by taking samples from a large quantity (usually 20 tons) of raw material and then analysing three samples drawn from the mixed samples. The raw materials were then passed through the commercial furnaces and the samples taken every half-hour from the furnace tappings. In the writer's opinion different furnaces and different methods of testing would probably give different results. The writer can, however, say that although he has bought and used thousands of tons of anthracite containing up to 0·04% of phosphorus, the analyses made by the chemists to the Acetylene Association have never shown that the permissible figure of 0·05% of phosphine was exceeded.

Summing up, therefore, the writer does not hesitate to say that with a good limestone, containing only traces of phosphorus compounds, it will be quite safe to use anthracite or coke containing up to 0·04% of phosphorus.

In North America a large quantity of Pennsylvania anthracite is used for carbide making, the size most generally used being slightly larger than South Wales "peas." These small pieces are supplied at a much lower price than the lump coal and analyses of these are given below :—

	Fixed Carbon.	Volatile.	Ash.	Sulphur.	Phosphorus.	Moisture.
Alden Wyoming	87·47	4·19	6·50	0·76	?	1·84
Susquehanna ...	75·02	6·18	17·47	?	?	1·33
No. 3	87·2	3·93	6·21	0·78	0·021	1·67

It is right to remark that the Alden Wyoming and Susquehanna analyses were communicated by the collieries, and that the American agents wrote as regards the former, that it is far better than it would show under boiler test. Analysis No. 3 was made at the Thornhill factory, and probably gives a fair idea of what the quality of the better class of American peas is.

The ash of No. 3 analysed as follows: Silica, 54·45%; alumina, 32·4%; oxide of iron, 6·53%; lime, 1·81%; magnesia, 1·14%; sulphur, 0·20%.

The gas obtained from some of the best South Wales anthracite was found to analyse as follows:—

	No 1.	No. 2.	No. 3.
Cubic feet per ton ...	2906	3078	2502
Illuminating power ...	None	None	None
Sulphuretted Hydrogen	Traces	0·30%	0·20%
CO_2	1·50%	1·20%	2·10%
O	0·94%	0·90%	1·10%
CO	2·92%	2·10%	2·90%
Marsh gas	13·99%	14·20%	13·80%
Hydrogen	61·63%	59·10%	58·70%
Nitrogen	19·02%	22·20%	21·20%

Coke.—As is well-known, hard coke, known in the trade as foundry (best quality) or blast furnace (second quality) coke is made from caking coal. With the increasing use of washing machinery, this kind of coke, with a fairly low figure of ash, tends to become available in larger and larger quantities, and as it is made in a great many fields, there is often considerably less difficulty in obtaining a reliable guarantee of quality than is the case with the South Wales anthracite coals.

The greatest drawback to the use of coke is, firstly, the large quantity of moisture which it often contains when despatched from the coke ovens (owing to its being quenched with water when made, and often allowed to stand in the rain for weeks or months), and which it often collects on the journey to the carbide factory, or when stored at the carbide factory, and secondly, the high percentage of ash.

Dealing first with the moisture, it may be said that it is quite unsafe, as a general rule, to reckon on less than 6% of moisture; in the case of shipment by sea, when the coke is often exposed to heavy rain at the port of despatch and arrival, the figure of moisture will sometimes reach 12%, or even more. Cases are known to the writer of consignees of cargoes of coke having claimed—and obtained, on proving their case—an allowance of 12% for difference in weight between that figuring on the bill of lading and that actually weighed out on arrival in South America.

As regards the ash, very few coalfields indeed produce coke having less than 7% of ash, even where the coke is made from washed coal.

Some typical analyses are given below.

From these figures it will be seen that the better brands of coke are usually fairly low in phosphorus.

	Fixed Carbon.	Ash.	Sulphur.	Phosphorus.	Moisture and Loss.
South Wales ..	91·4	5·09	0·728	0·018	2·74
„ ...	94·5	4·68	0·731	0·014	—
„ ...	89·74	7·5	0·26	0·049	—
„ ...	89·74	8·60	0·26	0·0075	1·40
Newcastle ...	91·5	6·68	0·7	0·03	—
Yorkshire	88·4	6·68	0·9	Trace	4
United States ...	85·1	8·60	0·97	„	3·8

South Wales undoubtedly stands at the top of the tree as regards high quality. Some of the coke-makers in that district will guarantee 6% of ash, and upon premium being paid, will supply a coke giving as little as 4½% of ash. Some of these cokes are, however, too high in phosphorus.

Next, as regards suitability for carbide-making, come some of the cokes in Yorkshire. In the writer's experience, these cokes surpass the best usually shipped from Newcastle. Some of the German (Westphalian) cokes are also of excellent quality, as shown by the following analysis, kindly made specially for the writer at the instigation of Director Papentin, of the Bergwerksgesellschaft Hibernia :—

Sort.	Fixed Carbon.	Volatile.	Ash.	Sulphur.	Phosphorus.	Magnesia.
Shamrock	89·60	2·80	7·60	1·04	0·21	0·114

The volatile of this coke consisted of 0·34% of hydrogen, 0·80% of nitrogen, and 1·660% of oxygen. The latter element was found by difference, and is probably rather higher than would be found in extended practice.

The figures for moisture given in all the preceding analyses are totally misleading as a basis to judge what percentage of moisture will be found on arrival at the carbide factory.

Although coke has the disadvantages dealt with above, it has certain advantages which more than make up for its disadvantages. The furnaces start more easily on coke—due probably to the fact of coke being a better electric conductor than anthracite—work more easily and last, but certainly not least, the consumption of electrode is considerably lower with coke than with anthracite.

One peculiarity of coke ought to be mentioned, because although it causes no trouble in actual use, it leads to considerable trouble in trading; we refer to the high percentage of iron.

It is no unusual thing to find up to 2% of oxide of iron in coke, owing to the latter being made from coal containing a much higher percentage of iron pyrites than is the case with anthracite.

The iron pyrites causes the formation of ferro-silicon in the carbide furnace. In ingot carbide, its presence causes little trouble, as the iron is disseminated throughout the mass of carbide; the customer does not notice it and therefore does not worry about it.

In tapping furnaces, however, the matter is different. The ferro-silicon tends to accumulate at the bottom of the furnace, owing to its higher specific gravity.

From time to time this ferro-silicon runs out with the tapped carbide. A portion of it can, as a rule, be detected, and usually a premium is paid to the workmen in the crushing room for picking out as much as possible. When, however, the lump of ferro-silicon is embedded in the carbide, it is, of course, practically impossible to detect and remove it, and it is usually discovered by the consumer in his carbide sludge. However good the carbide may have been, the consumer will usually lodge a complaint, even if the whole drum of carbide (including the ferro-silicon) has given more than the average of 4·8 feet per lb. (300 litres per kilogramme) demanded by the rules of the Acetylene Associations.

On the other hand, the same consumer will usually be perfectly happy if there is ten times as much impurity in the shape of unconverted lime. In the latter case he will probably get a beautiful white sludge (residue), and will probably not even notice if the gas-yield is slightly too low.

There is, unfortunately, one bad feature about the presence of ferro-silicon in calcium carbide, viz., the possibility, remote though it be, of an explosion occurring in a drum of carbide owing to a spark being set up by a piece of ferro-silicon striking another piece of ferro-silicon, or a piece of metal, violently.

The report made by the British Home Office experts, Messrs. Dupré and Lloyd, in connection with the well-known fatal accidents caused by ferro-silicon during transport, points clearly to the possibility of such a spark being set up; indeed, it can be produced in any laboratory,

Happily the danger from this cause, as stated above is exceedingly remote, only three cases being known to the writer in the case of tens of millions of drums handled, in which the possibility existed of an explosion being due to this cause, and in only one case was any harm actually done to the person. Even in these cases, it could not be clearly established that ferro-silicon was the direct cause.

In each case the explosion happened in the same way, viz., by a drum of carbide being allowed to fall heavily to the ground, and there was no doubt that no explosion would have taken place if the drums had been handled with reasonable care.

LIMESTONE.—*General Remarks* The writer has so often been asked what travertine is, whether marble is limestone, etc., that this must be his excuse for the following general remarks.

The marbles are limestones which through the action of heat and pressure have become more or less crystalline. They are usually suitable for carbide making, but are not, as a rule, so pure as good mountain limestones. Calcareous tufa and travertine are more or less compact limestones deposited by water springs or streams. They are largely used in Italy for making carbide. Some are excellent for the purpose ; others distinctly bad.

Mountain limestone is a name speaking for itself. It is the stone composing the "limestone ranges" known to most of us, perhaps the most brilliant example known to English people being the magnificent stone found in the Buxton and Settle hills, which furnish the bulk of the very pure lime used by the chemical manufacturers in the Liverpool-Manchester area.

Oolitic limestone, so-called because of its resemblance to a mass of fish roe, is made up of small rounded grains of carbonate of lime. Oolitic limestone is the staple limestone found in Gloucestershire, Oxfordshire, etc. It is usually considerably less pure than is required for carbide, the figures of phosphorus, silica, iron and alumina being all usually above the maximum allowable.

Chalk is a fine-grained limestone consisting of finely comminuted shells. It is sometimes of fairly good quality, as the analysis of Kent chalk farther on shows, but is usually too high in silica for making good carbide.

Magnesian limestone is limestone mixed with more or less magnesia. Samples have been repeatedly sent to the writer by would-be carbide makers, and as its appearance is usually very fine, the senders have been woefully disappointed to learn that it was useless for carbide making, although it is more advantageous than pure limestone for the manufacture of building lime, as it can be burnt with less fuel.

The principal impurities present in the limestone used for carbide making are magnesia, alumina, silica, iron oxide, sulphur and alkalies. The last-named have never been found by the writer to any appreciable extent in the stone used by him.

It is, of course, of the utmost importance to bear in mind that as 1,000 kg of good limestone produces less than 560 kg of lime, it requires approximately two tons of stone to make one ton of lime, and as the chief impurities in the stone are not driven off in the burning, a ton of lime will contain most of the impurities of two tons of stone. A limestone, for instance, containing 1·65% of silica will usually yield a lime containing 3·1% and above of silica, depending on the system of kiln employed.

In the old days of the ingot furnace little attention was paid to the quality of the lime. However poor the raw materials, the ingot furnace did its work and turned out carbide of beautiful crystalline appearance, and as the price of the commodity was exceedingly high, a low production did not much matter.

When the tapping furnace began to oust the ingot furnace, it was found that certain impurities, notably magnesium and aluminium compounds, caused great trouble in the furnaces, while others, such as phosphorus and silicon compounds, although causing little or no trouble in the working of the furnaces, caused trouble in the product and the time soon came when carbide users would no longer put up with the unpleasant haze caused by phosphorus, and the trade made emphatic remarks when excess of silicon and magnesium made its presence felt in the gas pipes and burners.

MAGNESIUM IN LIMESTONE.—Dealing with magnesium compounds first of all, it has been a generally accepted idea that a limestone containing more than 0·5% of oxide of magnesium was unuseable for carbide manufacture, the idea spread by the chemists being that magnesium had the property of coating each atom of the calcic raw material with a kind of glaze, which prevented it entering into chemical union with its partner atoms of carbonaceous matter.

This theory has to a great extent been upset in actual manufacture and to-day limestone is freely used containing 1% of magnesia. Indeed, at one factory in South America, with which the writer is connected, a good carbide (producing considerably more than 4·8 ft. per lb. =300 litres per kg) has been turned out for years with a limestone containing the following high figures of magnesia :—

Silica -	0·99 per cent.	0·94 per cent.
Oxide of iron -	0·47 ,,	0·27 ,,
Magnesia - -	1·45 ,,	1·29 ,,

It will be noted that, fortunately, the silica figure was not unfavourable.

The use of this limestone was, however, expensive, for it required a special—and very expensive—coke in order to keep the production per unit of energy up to a reasonable figure. The use of it was only possible through the absence of any competing factory.

Although the above experience shows clearly that a fairly high figure of magnesia will not interfere with the production of a good quality of carbide, there is no doubt that it interferes with the easy working of the furnaces, especially the tapping, and it is therefore very undesirable that the limestone should contain more than ½% of magnesia.

ALUMINA.—Very much the same remarks apply to the aluminium compounds, although in the writer's experience aluminum causes far less trouble than magnesium. Fortunately, moreover, an unduly high figure of aluminium compounds is rarely found in any reasonably good limestone, even in such as contain an excess of magnesium compounds, as the analysis given farther on will show.

Aluminium compounds are, however, said to be partly the cause of the formation of ammonia in the acetylene. Caro states that aluminium combines with the nitrogen in the coke to form aluminium nitride in the carbide. This nitride, when acted upon by water, produces ammonia. In connection with this the reader may be referred to Mr. Gatehouse's report, reproduced farther on.

Silicon in Limestone.—It is a generally accepted idea that 2 or 3% of silicon more or less does not matter in carbide making. This idea probably owes its origin to the fact that a fairly high figure of silicon compounds does not prejudicially affect the manufacture of the carbide. This is quite true; indeed, in the writer's experience an excess of silicon has much the same effect in the carbide furnace as in the steel furnace, *i.e.*, it lowers the temperature at which fusion takes place and thereby increases the production. At the same time it facilitates greatly the tapping of the furnaces, owing to the fluidity of the carbide being increased.

But when we turn to the quality of the product, the writer is bound to say that to-day, now the phosphorus-haze trouble has practically ceased to exist and nearly all factories turn out carbide with the regulation minimum gas-yield, or very near it, excess of silicon and magnesia gives rise to more complaints than all other causes put together.

Directly the silica figure much exceeds 2% and there is also a considerable figure of magnesia, trouble will arise with the carbide consumer sooner or later, this trouble usually being the stopping up of the gas pipes and burners with a brown dust which rapidly accumulates. This dust will, upon examination, be found to consist mainly of carbon, and its presence is to be attributed to overheating in the acetylene generator and consequent polymerisation of the acetylene.

Under such circumstances the blame is usually set down to faulty design of the generator. The writer has, however, followed up a large number of cases of this description with carbide from several factories, and in every case, when tapped carbide was in question, he has found that there has been an excess of certain impurities in the raw materials used for the manufacture of the carbide.

This would seem to point to the fact that these impurities tend to cause overheating in the acetylene generator, the overheating being, however, usually confined to generators of the "water-to-carbide" type. A lengthy series of experiments carried out at the writer's request by Mr. F. W. Gatehouse, Chemist to the British Acetylene Association, would seem to point to nitrogen being one of the impurities which cause the overheating. Mr. Gatehouse's report is so interesting that it is reproduced in full below:—

"EXPERIMENTAL INVESTIGATION INTO THE ABNORMAL WORKINGS OF CERTAIN SAMPLES OF CARBIDE.

The carbide used in this investigation was received on July 20th from the Hull Carbide Company, in lumps of from 2 to 3 inches.

A determination of the gas yield under standard conditions, that is apportioning the flow of water so that it should be always in excess of the carbide actually attacked, gave 4·87 cubic feet per pound (304 litres per kg) varying from 5·01 cubic feet (313 litres) to 4·73 cubic feet per pound (296 litres).

The lime residue was quite white, but possessed a distinct odour not usually noticed in residues from carbide.

FIRST SERIES OF EXPERIMENTS.—The gas was burnt in four burners forwarded from your firm. They were single-jet burners, stamped "crescent." The working pressure at the burners varied from 3·5 to 3·75 inches. 54

litres, or nearly 2 cubic feet, were consumed in 50 minutes, with the result that one burner had a smoky distorted flame and was quite useless, the remainder burning nicely.

Six other burners were now put up under similar conditions, 3 being single and 3 double-jets of various make, burning from 14 to 21 litres per hour. Two of the single-jets of different make gave out after 5 hours work, whilst the double ones showed no signs of deterioration.

The generator from which these experiments were conducted was provided with a water washer, but not with any other purifier. The same arrangement of apparatus was used throughout the whole of these experiments, except where specially mentioned.

It is thus seen that the type of burner has a great influence on the combustion of the Acetylene. With the carbide under test none but the most perfect double burners should be used.

SECOND SERIES OF EXPERIMENTS.—These were made with a different type of machine of the water-drip class, the amount of carbide used being the same as before, but the water-drip being limited to 80 c.c. in 15 minutes. Under these conditions the single-jet burners began to flare and smoke more or less in one and a half hours, and the lime residue was brown and dark coloured in patches, showing that some polymerization had taken place with this limited supply of water.

In another experiment with the same machine using twice the amount of water and the same amount of carbide, there was no polymerization, and the burners burnt normally. This shows the necessity of using an exces- of water in all types of apparatus, from the commencement of generation to its close. This point is emphasised in the following experiments, which were arranged so as to use the smallest quantity of water capable of decomposing the carbide in the first apparatus, but using one receptacle instead of a series of separate trays for carbide.

THIRD SERIES OF EXPERIMENTS, with 500 grammes of carbide in one receptacle, and water dropping at the rate of 25 drops per minute for 10 minutes; then at the rate of 10 cubic centimetres per minute, so as to keep 4 burners going.

This experiment was continued for about 5 hours until all the carbide was decomposed. The generator was very hot, and when opened a quantity of *dry brown powder* was found at the top, gradually mixed with lighter coloured powder, until at the bottom of the carbide container true white lime was found. The water in this machine is admitted at the bottom and sides of the carbide receptacle. The wash water was of yellow colour and contained *Ammonium Sulphide* of sufficient strength to produce a dense black precipitate of Ferrous Sulphide when added to an iron salt (Ferric chloride used). The volume of gas obtained from this experiment was only 124 litres or 248 litres per kilogramme, or 3·97 cubic feet per pound, instead of the 313 litres (5·01 cubic feet per lb.) obtained under standard conditions.

In this case the polymerization had been very great, with consequent diminution both in the volume of the gas evolved and the quality of the light produced. Deficiency of gas, 65 litres per kilo.

The same experiment was performed under similar conditions with a sample of Norwegian carbide. There was a streak of yellow slime in one spot, but no dry yellow powder, and the wash water was practically free from Ammon-Sulphide. In this case also there was a diminution of Acetylene evolved, amounting to 38 litres. per kilo, in comparison with that evolved under standard conditions:—

Volume under standard conditions,	311	litres per kilo
Volume under deficient water,	273	,, ,, ,,

The volume of water used was always more than sufficient to decompose the whole of the carbide, but not enough at any given moment to prevent polymerization, which would be intensified by the impurity afterwards found in the carbide. See next experiment.

Fourth Experiment with carbide complained of.—500 grammes in one receptacle, 6 burners turned on and off occasionally, so as to vary the amount of gas burnt.

Time during which experiment lasted, 7 hours.

Total water used in generator to attack the carbide, 1450 c c., allowed to run in at the rate of about 200 c.c. per hour.

Uncombined water run out from generator,	570 c.c.
Water combined with carbide and lime,	880 c.c.

The top of the carbide cylinder was, at the conclusion of the experiment, found covered with brown powder as before, the wash water was yellow, and the lime residue after standing smelt very strongly of *Free Ammonia.*

Burner No. 1, single-jet, soon became useless; a black mass of carbon protruded from the orifice, soot becoming deposited on everything near.

Volume of gas produced - -	262	litres per kilo.
Deficiency from standard running	51	,, ,,

5TH EXPERIMENT.—Same generator, but carbide in 7 trays, 500 grammes used as in previous work. 6 burners turned on and off occasionally.

Time of running 3 hours.

Water used 2400 c.c.

Volume of gas generated 150 litres = 300 litres per kilo, or 4·81 cubic feet per pound, as in the standard experiment.

The whole of the lime residue, together with the wash water from this experiment, was distilled into a measured volume of standardized acid, and the ammonia generated in this way titrated. It was thus found that the lime residue contained ·85 per cent. of ammonia. It is therefore evident that this carbide is manufactured under conditions in which nitrogenous compounds are so fixed that when the carbide is treated with water, ammonia is generated as well as acetylene. Not knowing the conditions under which the manufacture is carried on, it is impossible for me to state the source of this nitrogen, but as ammonia sulphide has several times been found in the wash water, it is possible that coal containing both sulphur and nitrogen may be the source. It is pretty certain that the sulphur is derived either from the coal, or from sulphates in the limestone, but the nitrogen may be derived from the air as in the preparation of Cyanamide. Should this prove to be the case, then the ·85 per cent. of ammonia found by me in Experiment No. 4 would be equivalent to 2 per cent. of Cyanamide.

The conditions of manufacture should apparently be modified so as to prevent the formation of this nitrogenous compound in the carbide.

At the time of writing the additional investigations still being carried on have not been concluded, and it is of course possible that the trouble attributed to sulphur and nitrogen is in reality due to other impurities in the raw materials."

The writer's experience is, however, that an excess of silica and magnesia usually produces a carbide which decomposes excessively quickly, and therefore sets up a high temperature, when the carbide is brought into contact with a comparatively small quantity of water.

Excess of silica does not, however, always act in this way; very much depends upon the form in which the silica is found. Many writers contend that if the silica is low in the lime, it may be proportionally high in the coke or coal, or *vice versa* ; in other words that it is the total quantity present in the mixture of raw materials which is the important factor. Such is not the experience of the writer ; on the contrary sad experience has taught him that whereas, for instance, anthracite with 3% of silica causes unpleasantness, the trouble does not exist with coke containing a much higher figure. Further a limestone with a high figure of silica cannot be offset by means of an anthracite with a very low figure.

The reason why the high figures of silica in the coke mentioned above did not cause trouble is probably because the coke contained also a very high percentage of iron, without doubt due originally to iron pyrites. The iron and silicon undoubtedly combined to form ferro-silicon ; this is most clearly evident, for all the carbide made with the coke in question contains an abnormal quantity of ferro-silicon, chiefly in the shape of small shot-like nodules. This ferro-silicon appears not to interfere with the working of the furnace in any way, and of course has no influence on the gas; indeed the writer has repeatedly found that a high percentage of ferro-silicon has indicated a good quality of carbide. More complaints—practically always unfounded—are, however, due to pieces of ferro-silicon (usually called "slag" by the customer) being found in the sludge than to all other causes put together.

Silicon in the limestone is, however, quite a different matter. It is never, in the writer's experience, accompanied by sufficient oxide of iron to facilitate the easy formation of ferro-silicon, and when the figure is high, it causes trouble in the quality of the carbide, although it in no way interferes with the working of the furnaces.

In a recently published work it was stated that a figure of 5% of silica in the limestone would not interfere with the work of the furnace. This is quite possible, indeed probable, but the user of the carbide would probably make unpleasant remarks.

Summing up therefore the writer does not advocate the use of lime containing more than 2 to 2·5% of silicon compounds, equivalent to 1 to 1·25% in the limestone.

IRON IN LIMESTONE.—Nearly all limestones contain a small percentage of oxide of iron. This is, as already stated, mainly converted into ferro-silicon in the furnace and causes no special trouble either in the manufacture or use, beyond that already dealt with under the heading coke, and, of course, the loss of energy for converting the iron oxide into a useless product giving no acetylene.

PHOSPHORUS IN LIMESTONE.—We next turn to those impurities which do not affect the manufacture of the carbide, but make their presence felt chiefly or entirely in the product itself. Of these undoubtedly the most objectionable is phosphorus and in contradistinction to what has been said about silicon, the writer's experience is that the total quantity of phosphorus in carbonaceous and calcium raw material must be taken together in order to ascertain whether the two materials, when used together, will give a satisfactory result. In the writer's experience, the maximum figure for the two raw materials, should not exceed 0·05% of phosphorus. In very many cases this figure is supposed to be exceeded, but in all probability the excess is in appearance, rather than in reality. The phosphorus in both coal and limestone is usually exceedingly irregular; in other words, the phosphorus is usually found in pockets, so that if the sample tested should by accident have come wholly or in great part from one of these pockets, an unjustifiably high figure of Phosphorus will result in the analysis. The only way to obtain an approximately correct figure for the coal (if anthracite be used) is to take numerous samples from all parts of a large consignment, say 500 to 1,000 tons, grind up the whole of them, thoroughly mix the whole and draw at least three samples for analysis.

For years carbide makers have worried over small percentages of phosphorus compounds in the limestone, but overlooked the infinitely larger quantity usually found in the coal, or have believed that the phosphorus in the coal is volatalised, but that in the limestone not. The writer, however, knows that the greater part of the phosphorus in the coal passes into the carbide.

Fortunately matters are to some extent simplified by the fact that it is extremely rare to find even as much as 0·02% of P_2O_5, or other phosphorus compounds, in any good limestone, as the analyses on page 107 will show.

As the quantity of phosphorus in the carbonaceous matter is usually so erratic, the writer would hardly care to use a lime containing anything more than traces of phosphorus, unless he were absolutely sure of getting coke from a known phosphorus-free field to use with it.

When, therefore, anthracite is used, or coke from a phosphoric field, about 0·01% of phosphoric acid should be the maximum in the limestone.

Let us say here, at once, that the idea, so carefully fostered in Government Regulations and other publications, that an excess of phosphorus can cause spontaneous ignition, is pure moonshine. The writer has never met with a single case of spontaneous ignition of this kind at any of the seven carbide factories he has been connected with, nor has he ever been able to obtain anything like an authenticated case from any other factory. But this absence of proof fades into insignificance when the fact is considered that at one of these factories carbide was specially manufactured for vine dressing purposes, with an abnormally large percentage of phosphorus, infinitely larger than the worst specimen of lighting carbide history has any record of. No spontaneous ignition occurred with this carbide and all attempts made to produce spontaneous ignition under usual conditions totally failed. Spontaneous ignition did occur with the dust from this carbide, but as the same thing occurs at practically every factory where dust, even from the purest carbide, is exposed to wet, it is clear that the ignition was not caused by the phosphorus, but through the high temperature set up when any carbide dust comes into contact with water.

Sulphur in Limestone.—Very much the same remarks apply here as mentioned previously respecting the sulphur in coal and coke. While a small part of the sulphur does apparently pass into the carbide, it must not be forgotten that the greater part of it remains in the sludge of the carbide. Fortunately again appreciable quantities of sulphur are rarely found in high-class limestones, so that the general tendency nowadays is to pay little attention to the question of the sulphur.

Arsenic in Limestone.—Here again we have to deal with an impurity, the danger from which exists apparently only in Official Regulations, which, like the proverbial sheep following a leader, go on insisting year after year, with a perseverance worthy of a better cause, that carbide must not contain so much arsenic compounds as will produce prejudicial quantities of arseniuretted hydrogen.

Has anybody ever seen such carbide? The writer has never seen, or heard of, a single sample of such carbide, nor even met with a coal or limestone used for carbide making containing even appreciable traces of arsenic.

Summing up therefore the maximum quantities of impurities permissible in a good limestone for carbide should be about 0·50% of Magnesia (MgO); 0·50% of Alumina and Iron Oxide, 0·01% of phosphoric acid (P_2O_5); about 1 to 1·2% of Silica (SiO_2); and only traces of sulphur. This corresponds roughly to a stone containing about 97 to 98% of carbonate of lime.

Such limestones are readily obtainable in many districts as most of the following analyses show :—

	Carb. of Lime.	Magnesia.	Alumina & Iron Oxide.	Silica & Silicates.	Phosphorus.	Sulphur.	Water.
Bellegarde ...	99·36	0·06	0·08	0·32	none	trace	—
Boulogne ...	98·51	0·32	0·44	0·48	0·03		—
Gotland ...	98·11	0·14	0·36	1·26	trace	„	—
Buxton	99·01	0·607	0·16	0·22	0·008	0·172	—
Minnesota ...	98·08	1·52	0·131	0·83	trace	trace	—
Wales (S.) ...	99·01	none	0·133	0·86	none	„	—
„ **(C.)** ...	99·19	0·23	0·21	0·53	„	none	—
„ **(C.)** ...	98·92	0·40	0·24	0·33	„	„	—

On the other hand the following analyses deal with stone which the writer would not recommend for making first-class carbide :—

	Carb. of Lime.	Magnesia.	Alumina & Oxide of Iron.	Silica & Silicates.	Phosphorus.	Sulphur.
Kent (Chalk) ...	97·54	0·34	0·35	1·88	trace	—
W. of Ireland ...	93·2	0·89	0·40	1·44	0·044	0·18
S. Norwegian ...	95·5	0·50	0·41	2·97	trace	trace
Foyers	96·35	2·56	0·24	0·85	none	none
W. Norwegian ...	95·2	0·52	0·65	3·30	trace	trace
Buckingham (Chalk)	91·82	0·26	0·22	1·70	„	„

Physical Requirements of Limestone.—As already mentioned, it is very important that the limestone for carbide making should decrepitate as little as possible, for the dust produced is simply waste, which would cause in the furnaces far more trouble than it is worth. Dust of any description prevents the free escape of the gases set up by the reactions, and leads in addition to a waste of raw material, which, if open furnaces are used, is spread about the factory, increasing greatly the dust nuisance which causes trouble enough under any circumstances.

The stone should be thoroughly well burnt, rather over than under-burnt, for if under-burnt, the cores of unburnt stone in the centre of the lumps of lime will quickly make their presence felt in the furnaces.

Many experts hold that old lime is preferable to fresh lime, but it is difficult to see the reason for this belief. Old lime—by which is meant lime three to ten days old—must inevitably have absorbed a certain quantity of moisture from the atmosphere, which has to be evaporated at a considerable expenditure of energy. What advantage old lime presents which compensates for this loss of energy seems hardly clear.

CHAPTER XVI.

RESULTS OF MANUFACTURE.

One of the worst—if not the very worst—enemy the carbide manufacturer has had to contend against has been the text-book manufacturer who, without the slightest knowledge of the commercial working of a carbide factory, has sat down and evolved out of his scientific mind the fact (!) that carbide could be put on the market at about £4 per ton.

To this kind of statement is due in no small measure the enormous over-production which made the manufacture of carbide one of the least remunerative branches of modern industry, and causes even to-day the Damocles sword of insensate price-cutting, and consequent ruin, to dangle over the heads of the manufacturers, suspended by the frail thread of price conventions.

Even to-day the pernicious effect of these misleading calculations is apparent, the writer having only just received a copy of a letter from a gentleman who proposes to start a carbide factory because he can obtain cheap lime (by which he apparently understands lime costing 15s. per ton), and electric energy costing only (!) ¼d. per unit (or, say, £8 6s. 8d. per kilowatt-year). And the amount of power available is the magnificent figure of 500 e.h.p., a quantity altogether too small to secure economical manufacture, even if the cost were really cheap. It is safe to say that there is not a carbide factory in Europe, even those right up in the mountains of Switzerland, which could not land carbide in England even at the door of this suggested works, at a lower cost than the latter could produce at.

The writer dwells rather fully on the points mentioned above, because the object of this book is to serve as a guide for the first steps of the aspiring manufacturer and nothing could be worse for the latter than to believe the fairy tale, repeated to the writer over and over again ad nauseam, that "all you require is a ton of lime costing 15s., three-quarters of a ton of coke costing 15s., a horse-power-year of electricity costing 35s., labour 25s., so that your carbide costs you £4 10s. per ton."

It does not even seem to have occurred to these ingenious gentlemen that packing costs something, and that nearly every factory in Europe failed to pay a dividend when prices were at £8 to £9 a ton, although in most cases their power cost actually less than the above-mentioned figure of 35s. per horse-power-year.

Let us go farther and reckon out the probable cost of production at a small factory with 500 h.p., taking as basis the results obtained to-day in an up-to-date carbide factory. Let us assume that the factory is situated in a favourable position, such as Cardiff (where coke is obtainable at the door of the factory, but high class lime would have to be railed), or at Bristol (where cheap, but not very good, lime is available, but coke or anthracite would have to be railed).

To begin with, 10°/₀ would have to be deducted, with so small a plant, for power required for crushing the raw materials and carbide, for the elevators, for the pumps and other machinery, for lighting, and for loss in the transformers. The power available for the carbide furnace would therefore be only 450 e.h.p. and the nett cost of the power would be increased by 10°/o.

Let us assume that a production is attained of 1·3 ton of raw carbide per nett horse-power-year of 8,000 hours (a figure which the manager will find very considerable difficulty in attaining with so small a plant); the production will therefore be 450 × 1·3 = 585 tons per year. But we have not yet finished with our deductions. This is *raw* carbide and it still has to be crushed. With so small a production, it will be impossible to keep the crushing plant running regularly and the carbide will have to stand about, so that the manager will be fortunate if his loss in dust is only 6 to 7°/o. Let us take 6°/o. The quantity of saleable carbide will therefore be 585 tons, less 6°/o, say, 550 tons. Of this, by the way, a fairly large proportion will be carbide of $\frac{1}{32}$ to $\frac{1}{8}$ inch, which may perhaps be sold, but in all probability will lie untouched for years and ultimately be returned to the carbide furnace as raw material.

Ignoring any loss which may occur through unsaleable carbide, our figures therefore now read 585 tons of raw carbide and 550 tons of packed carbide. We will now see what this carbide will cost:—

	£	s.	d.
Lime.—0·95 ton for 585 tons, say 555 tons at 15s. per ton delivered at works ...	416	5	0
Coke.—0·6 ton for 585 tons, say 351 tons, at 23s. per ton delivered at works ...	403	13	0
Carbons.—0·03 ton for 585 tons, say 17½ tons at £16 per ton delivered at works	280	0	0
	£1,099	18	0

Labour—Here we begin really to touch upon the weakest spot of small factories, for a furnace of say 2,000 h.p. can be run with almost as few men as a furnace of 500 h.p. A single tapping furnace cannot, without running grave risks, be worked by less than three men, and as three shifts of eight hours each have to be worked, the furnace room alone will call for nine men, three of whom must be shift foremen. As the production depends to a great extent on the workman and the work is laborious, good men are required, but a wage of 25s. only is assumed, although the writer would not know where to find such men in England to-day :—

	£	s.	d.
9 Furnace room men at 25s.	11	5	0
1 Electrode Mounter	1	15	0
4 Men for Carbide crushing and packing, at 20/-	4	0	0
2 Men for raw materials and elevators, at 20/-	2	0	0
1 Night Foreman in charge	2	10	0
3 Boys for electrodes	2	5	0
1 Manager	3	0	0
1 Boy Clerk	0	15	0
1 Odd Man	0	17	0
Total ... 22 Men, costing per week	£28	7	0

	£	s.	d.
Or, per 52 weeks (the men and a couple of Bricklayers will be required for repairs, when the factory shuts down for overhauling)	1474	4	0
Employers' Liability Insurance, say ...	15	0	0
Rates and Taxes	50	0	0
Fire Insurance	80	0	0
Outside Electrical Help	50	0	0
Outside Repairs	30	0	0

Electric Current—500 h.p. for 8,000 hours, say, 2,984,000 units at ¼d.	3108	6	8
Power and extra labour for repairs during stoppages	15	0	0
Depreciation and Repairs—10% on £6,000 (the figure of 10% can be reduced considerably by cutting out various labour-saving devices, but in such case the cost for labour will be more than correspondingly increased)	600	0	0
Cost of raw materials (see above)	1099	18	0
Cost, therefore, for 555 tons of Carbide ...	£6522	8	8
Or, per ton	£11	15	1
Packing—20 drums at 1/6 (Note—since this calculation was made, the price has increased to 1/8)	1	10	0
(*a*) *Selling Costs*, including advertisements, travelling expenses, etc.	0	12	0
(*b*) *Allowances* for faulty carbide, or carbide damaged in transit, analysis of carbide and of raw material, auditing, Secretary, Director's fees etc.	0	10	0
Total net cost	£14	7	1

This figure may seem very high, but the writer may point out that at one factory, using 1,000 h.p., equipped regardless of expense, the cost, *exclusive of the items* (*a*) *and* (*b*) *above*, rarely sinks below £13 per ton, although the cost of power is only £3 10s. per Kilowatt-year. This factory, is, however, protected against foreign competition by an import duty of no less than £6 per ton.

Of course the weak spots in above cost-sheet are the excessively high cost for power and for labour. The picture, however, errs rather on the light side than on the dark, for the electric energy would probably be supplied in the shape of 3-phase current, necessitating for so small a power either the use of a furnace having three upper electrodes (which system for small units is certainly costly in carbon and raw material consumption and also in labour), or of three small furnaces. We have also said nothing about the payment of patent royalties, which are likely to figure to a considerable extent in the budget, if an up-to-date plant is to be provided.

Now, as a contrast, let us turn to the cost sheet of a large factory situated near the sea on the Continent and equipped with large furnaces, each taking 2,000 h.p. or above. In order to make the comparison as fair as possible, we take a factory, which, although running with very cheap power, has to import its carbon raw material from England and its limestone from another country, it being well known that some of the works in Norway import not only their coal, but the bulk of their limestone :

1. *Lime*—950 Kg. at 23/- per tonne (1000 Kg.)	1	1	10
2. *Anthracite*—620 Kg. at 22/-	0	13	8
3. *Carbons*—30 Kg. at £15 per 1000 kg. ...	0	9	0
Cost per tonne of carbide for raw materials	£2	4	6
4. *Labour*	0	19	3
5. *Salaries* and Office expenses	0	4	3
6. *Rates and Taxes*	0	1	1
7. *Fire and Employers' Liability Insurance*	0	0	7
8. *Miscellaneous* general expenditure ...	0	0	11
9. *Small* general *repairs*	0	2	3
10. *Cost of Power*	1	3	6
11. *Depreciation and replacement of plant* (10%)	0	6	0
12. *Depreciation and repair of buildings* (6%)	0	4	10
Factory cost per tonne of unpacked carbide	£5	7	2

See p-116 6 3

Factory cost per tonne of unpacked carbide	£5	7	2
The loss in dust was 3%	0	3	3
Nett cost per 1000 kg.	£5	10	4
13. *Packing*—20 drums at 1/6 (own manufacture)	1	10	0
14. *Selling costs*	0	12	0
15. *Allowances*, *Secretary*, head office charges, etc.	0	13	2
Total actual cost at works	£8	5	6

Unfortunately, even this cost cannot be taken as the final one, because factories dealing with water-power and electricity are peculiarly susceptible to breakdowns, stoppages through shortage of water and other troubles which interfere most seriously with the cost of production. For instance, the power-line of one carbide factory, although provided with modern arresters, has in the course of the last year been struck three times by lightning, each accident necessitating a stoppage of 3 to 4 days. During this time the usual expenditure at the factory has to be defrayed, although nothing has been turned out.

Again, many factories see their power very seriously reduced during two to three months every year, and in case of a dry season, sometimes five or six months.

Not very long ago, for instance, a very bad cloud hung over Norwegian factories. The dry summer had almost depleted the natural storage reservoirs, the lakes which feed the rivers in winter time, when no water runs into the streams, any moisture falling in the winter naturally taking the shape of snow and remaining unmelted. In such a case, if any early winter sets in, nearly all water powers are reduced by at least one-half for many months. During all this time nearly all charges go on at the factory, for it is impossible to dispense with any part of the trained staff, and the only saving in the labour bill will be in the shape of sending away a few of the labourers, the least highly paid of the whole staff. The furnaces will probably have a lower production and the items 4, 5, 6, 7, 8, 9, 11, 12 and 15 of the preceding cost sheet will almost double themselves.

Such accidents cannot be allowed for in definite figures per ton of carbide, but they *have* to be met and should be met by means of a reserve fund (which, unfortunately, few carbide factories have been able to accumulate in the past). Taking, however, the history of one of the oldest factories in Europe for the last ten years, the writer has found that it would have required a fund at the rate of no less thon 6s. 3d. per ton to cover the results of unforeseen troubles.

It is, therefore, safe to say that there is little money in carbide for the average factory at a selling price at the factory of less than £8 15s. to £9 per ton. At this price a few factories will still make a profit, but others will make a decided loss.

One fact, however, comes out from the foregoing figures, viz., that any Norwegian factory can, as long as there is no customs duty protecting English carbide, land carbide at the door of the typical 500 h.p. factory just mentioned at pounds less than the cost of manufacture of the latter.

CHAPTER XVII.

DETAILED WORKING RESULTS AND POWER PLANT.

Having dealt with typical examples of the working results as a whole, we will now turn to the details and examine the working results of each of the chief parts of the plant.

In the course of this examination many rather intricate technical and other calculations will occur, and as they may be of service in following the figures, we give at the end of this book the tables mainly used to base the calculations upon.

POWER PLANT.

It would take an entire book, or many books, to describe the results obtained in the infinite variety of power stations. It will suffice to say that in the majority of cases a power station for supplying energy to a carbide factory is nothing more or less than the ordinary type of electric station generating alternating current at high pressure, by which we mean a pressure of 5,000 volts and above.

It is, however, very important for the prospective manufacturer to know that a horse-power in a waterfall does not mean, by a very long way, a horse-power at the carbide furnace. In the first place, the average efficiency of turbines, working continuously at full load, cannot be put at more than about 80%. Secondly, there will be a loss of usually about 10% in the electric generators (dynamos) themselves. Thirdly, there will be a loss in the transmission line and in the transformers of at least 3½%, even if the line is short (here we would like to mention that the loss in transformers is usually far higher than the tests at the transformer factory would lead one to believe, because such tests are usually carried out when the transformers are almost cold, whereas they should be carried out when the transformers have reached the normal working temperature).

Lastly, there is the loss in the busbars which conduct the current between the transformer (or generator) and the furnace. This, as shown later on, will rarely be less than 1%.

Summing up, therefore, we have a loss of 20% in the turbine, leaving 80%,

10% (on 80%) in the dynamo ...	leaving	72%,
1% (on 72%) in the line	,,	71·28%,
3% (on 71·28%) in the transformers	,,	69·14%,
1% (on 69·14%) in the busbars ...	,,	68·45%,

A waterfall giving an effective power in falling water of 500 h.p. is thus shown to be reduced to 500 × 68·45% = 342·25 h.p. But this is not the end of the reductions. Another 5 to 10% has to be deducted, as already mentioned—and the smaller the plant, the larger will be the percentage deduction—for the power required for crushing and conveying the raw materials; crushing and screening the carbide; driving pumps for the cooling water and fans for dust exhausters, etc.; providing light for the factory, driving drum-making and other machinery, etc. If we take the power required for all these figures at the figure of 10% (and we cannot reckon on very much less in a very small factory), our power available for the furnaces themselves is reduced to only 61·6%, so that a 500 h.p. waterfall will only run a 308 h.p. furnace.

Lastly, we come to the very important deduction necessary for fluctuations in the waterfall itself. Very few factories indeed can rely upon regular supply, all the year round, of the full quantity of power which the carbide factory is equipped to take. In some countries, such as Switzerland, there will be floods in the spring, when the snow melts on the mountains, and a scarcity of water in the winter. In other countries, such as the United Kingdom, the floods usually come in the winter and the water famine in the summer.

All these considerations must be taken into account, for the greater the fluctuations, the more the cost of the power will be increased, while at the same time the cost of manufacturing will probably also be increased considerably through the factory having to bear the high charge for interest, upkeep and depreciation on a large part of the plant, which stands idle when power is short.

It can, therefore, very well occur that irregular power offered by a power company at $\frac{1}{15}$ penny per unit (kilowatt hour) may in reality be much dearer than regular power at $\frac{1}{10}$ penny.

The capital outlay for constructing a hydro-electric station varies usually between £15 and £30 per h.p.; it is, as a rule, nearer the latter figure than the former. In exceptional cases it will be considerably less than £15, but such cases are few and far between and are only found where nature has been bountiful enough to provide a water-power which requires very little dam or storage-work, very short in-take channels or pipe-lines, and a ready-made channel for carrying off the tail water.

The cost of power (electric energy) per horse-power and per year of 8,000 hours is usually round about 30s. (francs 37·50). Two cases are known to the writer where the power costs less than 20s. (francs 25) per horse-power-year, but in both these cases the huge over-production, and consequent unremunerative prices for the products manufactured, had driven the original companies into liquidation, and the works were acquired subsequently by other firms or companies for a small fraction of their original cost.

The other extreme is probably to be found in the case of the carbide works at Niagara Falls, where a price of $15 is stated to be paid per horse-power-year.

Our remarks respecting the cost of power would be incomplete if we did not deal with the question of obtaining the electric energy by means of gas or steam engines.

Gas and Steam Power.—Most of our readers will recollect the notorious advertisements of certain gas-engine makers, when suction gas began to loom large in the public eye, "20 horse-power-hours for a penny." This works out at about $\frac{1}{15}$ penny per unit, or about equal to Norwegian water-power at 30s. (francs 37·50) per horse-power-year of 8,000 hours, and the advertisements brought a large number of proposals forward to establish carbide works in British and foreign coal districts.

To the expert it is hardly necessary to say that the disappointment was great when it was found that this penny only represented the cost of fuel; the fact was entirely overlooked that, according to the figures published by J. R. Bibbins in the *Electric Journal*, the fuel for a gas-engine plant, with coal or coke costing only 12s. (fr. 15) per 2,000 lbs., represents less than one-fifth of the total cost of running the gas plant, so that this wonderful power-supply would in reality actually cost more than five times as much as Norwegian power, indeed, more than the total cost of manufacturing the raw carbide at most places on the Continent.

There is no doubt in the writer's mind that sooner or later the cost of generating current by means of blast-furnace gas, or coke-oven gas, or similar bye-product fuels, will sink to such an extent as to render these fuels formidable rivals of waterfalls. We are, however, not there yet.

For years the writer has investigated every opening for the utilisation of such fuels, but when it has come to cold figures, the beautiful prospects have faded away. Let us examine some typical examples. We will first borrow some figures from Prof. Vogel's work on "Acetylene."

According to Neumann (who, as chief engineer of the celebrated Otto gas-engine works, certainly ought to know), a gas-engine plant for utilising blast furnace gas will cost £10,000 per 1,000 b.h.p., to which must be added £4,000 for the electric plant. Neumann says that the plant should be written off in ten years (experience has since shown that this allowance for depreciation is too little). The running cost is therefore estimated by him as follows:—

Depreciation, 10% on £14,000 ...	£1,400
General expenses, 3% on capital cost	420
Attendance	200
Lubricants	620
Cost of the blast furnace gas ...	1,630
Interest and profit on the plant, 6%	840
Total cost per year	£5,110

Neumann further states that a gas-engine plant working with blast-furnace gas cannot be reckoned on for more than 300 days per year, whereas the minimum year with a waterfall is 330 days. When the writer thinks of the unfortunate experience one Welsh colliery has had with large horizontal gas engines, Neumann's belief seems justified. It is, however, only fair to state that in England the vertical engine, with its special facilities for quick repairs, now certainly averages a better year than 300 days.

In any case, however, the case as put by Neumann is bad enough, for even if we assume that the 10% depreciation covers the numerous repairs and that 1,000 B.H.P. is equal to 1,000 h.p. on the supply line of the dynamo, we still get a cost of more than £5 per horse-power-year, an impossible figure for carbide manufacture.

Other experts do not, however, share Neumann's views. The lowest estimate which the writer has ever met with is that published by Frank Foster in the *Manchester Guardian* of January 2nd, 1912. As it is far more exhaustively worked out than Neumann's figures and is extremely interesting, it is reproduced at considerable length below.

It should be pointed out that Foster's paper does not deal with blast-furnace gas, but with producer-gas, with bye-product recovery, and the fact should be particularly noted that Foster assumes that the bye-products will be sold for almost the same sum that the coal costs, so that, even after allowing for the cost of recovering these bye-products, his fuel will cost less than blast-furnace gas (it should be borne in mind that to-day probably no blast-furnace or coke-oven owner can be found who will sell his waste gas for a song). It will also be noted that the plant has to be on a very large scale to secure the results held out by Foster.

The scheme is based upon a steady load day and night, the whole year through, as for a chemical works, and for continuous current units which, Foster remarks, are cheaper than alternating current units.

The normal capacity is 3,400 kilowatts. Each engine will deliver 800 to 1,000 k.w., but will be rated at 850 k.w. in normal work. Five engines are provided for, therefore one will be in reserve—a very wise precaution. The capital outlay will be:—

Five generating units, auxiliaries and pipe work; switchboards, cables and crane; buildings and foundations; engineer, architect and miscellaneous (8%).	
Total cost	£58,200
Add cost for plant for recovering bye-products	21,500
Total cost	£79,700

The cost of coal is taken at 10s. per ton (which is about the price to-day of medium quality small coal); the oil consumption at 0·35 gallon (say about 1·6 litres) per engine per hour, the oil costing 1s. 6d. per gallon (say fr. 0·40 per litre). Water towers are assumed and that 12,000 gallons (say 54,700 litres) per engine per hour are circulated, involving a loss of 360 gallons (1636 litres) per engine per hour, at a cost of 4d. per 1,000 gallons (9 ctmes. per cubic metre). Stores are taken as costing about one-fifth as much as oil. For labour one man per engine is assumed, but not less than two people in the engine house at once. The heat value of the coal is taken at 13,500 B.T.U. (7,500 Cal. per kg.); the recovery producer efficiency at 65%; and the evaporation of the gas-plant boiler per pound of coal at 5 lb. if fired with gas from the producers, or 7 lb. if fired with coal.

The following prices are assumed for the bye-products: Sulphate, £13 per ton; tar, 10s. per ton; acid, bags and packing, £1 17s. per ton of sulphate. Three shifts per day are to be worked, and the average wage for the producer men is put at £65 per year.

The costs for running the gas-plant Foster estimates as follows:—

Coal		£12,500
Labour, 36 men		2,340
Chemist		150
Stores, repairs and maintenance ...		1,300
Acid and packing		1,652
Interest and depreciation, 10% ...		2,150
Total expense		£20,092
Sulphate recovered, 893 tons	£11,609	
Tar recovered, 1,250 tons ...	625	
Total recovered		£12,234
Net cost of gas		£7,858

Turning now to the engine house, in each shift the labour is stated to be:—

One leading driver, at per year ...	£130
One driver	91
Two greasers	130
Thus per shift	£351
Therefore for three shifts	£1,053
Proportion of chief engineer's pay ...	160
Total labour	£1,213

This figure does not include labour for repairs and maintenance, which is assessed at 1% on the total capital outlay. Other charges are:—

11,750 gallons of oil	£882
Stores	176
Water, 12,100,000 gallons	202
Total Stores	£1,260

If the costs for the gas-making and gas-engine plants are added together, we get the following:—

Gas making	£7,858
Stores	1,260
Labour	1,213
Repairs and maintenances	873
Interest and depreciation	5,820
Total cost	£17,024

Mr. Foster expects to get with this plant an annual output of 28,550,000 units, which is equivalent to working 24 hours per day during 350 days per year. On this basis he comes to the conclusion that his power will cost him 0·1431 penny per unit, or roughly, £4 15s. (fr. 119) per kilowatt-year of 8,000 hours, or £3 10s. per year of 8,000 hours and per Continental h.p. of 736 watts.

This result makes Mr. Foster's scheme of little value for free-trade England, but, in addition his figures are far too optimistic. The writer has access to the cost sheets for a plant of almost exactly this description, worked by an extremely well-managed company. The cost of the power, working continuously on the production of one chemical, is about 30% higher than Foster's estimate.

To further test the matter, the writer obtained estimates from two of the foremost British and German manufacturers of plant of this kind. Both estimates showed a cost of less than £4 per horse-power-year, but neither firm would give a *guarantee* of £5 per horse-power-year, even if they themselves found the staff for working the power station and the latter were entirely under their control.

In spite of all this, however, the writer firmly believes that gas-power is rapidly reaching the stage, when its use will prove lucrative for various electro-chemical and electro-thermic processes.

Before leaving this point, the writer may well be expected to say why, if no gas or steam plant can compete with foreign water-powers, he took steps to establish a carbide factory at Thornhill using steam-power. The answer is very simple. This factory, which at present is the only one in the world using steam-power, is also the only one using an intermittent supply, and this arrangement allows it to utilise boiler-power which otherwise would be mainly wasted. The actual cost of the power was therefore in no way the determining factor when the price to be paid for it was fixed.

CHAPTER XVIII.

LIME KILN.

Wherever possible, it should be the aim in works to compare the results actually obtained with those theoretically feasible, although this praiseworthy endeavour will be found extremely difficult to carry out as far as the actual manufacture of carbide itself is concerned.

For the burning of lime, however, very good data exist. The specific heat of calcium carbonate (limestone) according to Eckel is 0·22 and the temperature of dissociation is about 1,300°F. It is true that this takes no account of the impurities in the stone, but as a pure quality is usually employed by carbide factories, we can very well afford to ignore the impurities so far as the question of the quantity of coal required for burning the limestone is concerned.

As 100 lbs. of stone should theoretically yield 56 lbs. of quicklime the quantity of coal required would be :—

Using Coal with B.T.U.	Coal required per: 1,000 Kg of Lime.	Coal required per: 2,240 lbs. of Lime
11,000	127 Kg	284 lbs.
12,000	117 ,,	261 ,,
14,000	100 ,,	224 ,,

Richards gives 451·5 Cal. as being required to calcine 1 Kg of limestone. His figures are, of course, based upon an absolutely pure stone.

The writer has made enquiries not only in most European countries, but also in North America, and he is forced to come to the conclusion that the figures given by a well-known firm of kiln-builders in the United States (4 to 5 tons of lime per ton of coal burnt) are rather better than the average results, and that in good commercial practice the average fuel consumption of a modern contact kiln is approximately 224 lbs. per 1,000 lbs. of lime produced, and of a gas-fired kiln 240 lbs. In certain types of kiln these figures can, of course, be improved on. It will be seen, therefore, from the theoretical figures that there is still room for great improvement, but the writer, in spite of long and painstaking enquiries, has failed to locate any special form of kiln giving a better fuel consumption without some attending disadvantages.

By far the best results in actual work the writer has ever heard of were attained by a new type of gas-fired kiln tried by a friend of the writer's, a Settle lime-burner, some three years ago, the actual consumption varying from 341 to 381 lbs. per ton (2,240 lbs.) of lime produced (say 152 to 170 kg per 1,000 kg). There were, however, certain disadvantages in connection with this kiln, which led to its being constantly hung up, and the inventor apparently having no funds, and the lime-makers being unwilling to continue the experiments, the working was discontinued.

There is, however, one point in connection with these trials which, strange to say, is not referred to, even by the expert employed to supervise the experiments, viz., that the kiln was worked in a district which, upon reference to the geological map, the writer finds produces magnesian limestone only. Dissociation, in the case of a magnesian limestone, probably takes place at 600° to 700° C., instead of at about 900°C., as in the case of the non-magnesian stone required for making carbide. Eckel states that it requires 1,864,400 B.T.U. if stone containing 20% of $MgCO_3$ be used, as against 2,113,600 B.T.U. for 100% $CaCO_3$, or, roughly, 8% less fuel, but even taking this into account, the results obtained were certainly extremely good.

The following figures (for a works in North Wales) are given by Eckel in his text-book. The kiln is stated to be a Hoffmann and the ton is presumably the American one of 2,000 lbs. :—

Cost of quarrying, including tools	\$0·31¼	(1/3½)
Charging kiln	0·10½	(-/5¼)
Drawing kiln	0·07¼	(-/3½)
Wages of burners	0·07¼	(-/3½)
Fuel at 1·75 (7s. 3d.), say 0·214 ton	0·37½	(1/6¾)
Managing expenses, etc. ...	0·31¼	(1/3½)
	\$1·25	(5/3)

Twice, when in North Wales, the writer took particular trouble to get these figures substantiated, but without much success, and he was reluctantly forced to come to the conclusion that they were written in rose-coloured ink. We give below figures which show what may be reckoned on in good commercial practice, where the quarry adjoins the kiln :—

PER 1,000 LBS. OF LIME PRODUCED.

1. Stone required (the theoretical quantity required is 1,786 lbs.) ...	1910 lbs.	
2. Small coal consumed (calorific value about 11,500 units per 1,000 lbs.)	224 lbs.	
A much lower coal consumption was obtained with a better coal, but as the economical results were less favourable (owing to the much higher price of the coal), the cheap fuel was reverted to.		
	s.	d.
3. Labour (including fetching the stone and coal by tram trolley a distance of about 100 yards (90 metres) ...	1	0
This cost works out at about 2s. 2½d. per tonne of 1,000 kg. The kiln was provided with electric hoist, but could be improved by the addition of self-acting arrangements for loading up and weighing the stone and coal.		
4. Repairs (including re-lining once yearly)		6
5. Depreciation (5% of £800 divided over 6,000 tons of lime per year)		1½
6. Management, insurance, taxes, etc.	1	4

The cost of 1,000 lbs. of lime, basing on above figures, may be taken as follows:—

	s.	d.
1. 1,910 lbs. of stone at 2s. per 2,200 lbs. (1,000 kg)	1	8½
2. 224 lbs. of coal at 13s. per 2,200 lbs. (1,000 kg)	1	4
3. Labour	1	0
4. Repairs and renewals		6
5. Depreciation		1½
6. Management, insurance, taxes, etc.	1	4
Cost per 1,000 lbs. ...	6	0
Or per 1,000 kg. (2,200 lbs.	13	2

These figures of cost will, in most cases, have to be increased by about 5% in order to cover the loss in stone, in lime dust, and in coal. It will also be seen that they do not include any interest on capital. Where the kiln is situated at a distance from the quarry, the cost of transport must, of course, be added.

CHAPTER XIX.

FURNACES.

We will deal first of all with the production per unit of energy. In the first place, let us point out that all the figures given below refer to raw carbide, *i.e.*, to the saleable carbide in ingot form, as it comes from the furnace, thus before crushing and packing.

It is in the writer's opinion absolutely useless to state that a "furnace produces X kilogrammes of *packed* carbide per kilowatt day"—such an indication is a very crude guide, for it takes no account of the loss in dust. And this loss in dust varies enormously, according to the type of furnace and of raw materials used, and last, but certainly not least, according to the shape the carbide has to take before packing.

As regards the last-named point, it is quite clear that if one factory supplies 80 to 90% of its production in lump carbide, *i.e.*, carbide ranging from 1 to 3½-inch in size, its loss in dust will—or, at any rate, should be—far lower than that of factories which have to cater for markets taking mainly pieces of ¼ inch. Whereas in the former case the loss in dust should not exceed 5 per cent., the loss will in the latter case reach 15 per cent., or even rise as high as 25 per cent., if the carbide be soft and the crushing material poor.

Again it is often misleading to talk of production per horse-power-year. In the first place it is often overlooked that the British electric horse-power is 746 Watts. Furthermore the year seems to vary at every carbide factory. At one works known to the writer, the year consists of 330 days of 24 hours, say 7920 hours, the remaining part of the year being devoted to over-hauling, repairing, etc. At another, a very full reserve plant is kept, enabling the power to be used during the whole 365 days of the year, say for 8760 hours. In the latter case, therefore, about 11 per cent. more energy per year is available than in the former, making a comparison per year utterly unfair.

Again at some factories it is customary to measure the power at the terminals of the furnace; in other words, the measurements are taken on the secondary circuit, at points close up to the furnace. In other factories the production is based on the entire power taken, as indicated by watt-meters placed in the high tension circuit at the point where the wires leave the power station. In some cases again the energy is measured on the primary close up to the transformers.

It is clear that the second and third systems mentioned above cannot serve as a reliable basis, inasmuch as the figures of energy consumed will include the power required for lighting, pumping, crushing, etc., and, for instance, the power taken by the crushing machinery will vary considerably according to the amount of small carbide turned out.

In order to ascertain fairly the production of a furnace, the writer is of opinion that the power should be measured which is put into the actual furnace transformers through the primary circuit ; in other words, the loss in transformers and secondary circuit should be debited to the furnaces, but all power supplied to crushing machines, elevators,, etc., should be eliminated from the calculations.

Some types of furnaces require special transformers, entailing higher transformer losses than usual. Other furnaces again require busbars of greater length than usual. It is, therefore, only fair that each type of furnace should be debited with the transformer or busbar loss entailed by its particular design.

The following figures are therefore all based upon measurement on the primary side of the transformers, and include the loss in transformers and in the secondary circuit.

One most important point must, however, be dealt with here, *i.e.*, the influence of gas yield of the carbide on the production. Every carbide maker knows that the production rises rapidly as the gas yield goes down and vice versa. The following figures, published by Mr. Keller, of Paris, show the enormous difference in production caused by allowing the quality of the carbide to go down or up.

With	115 l	gas yield,	the production was	11·9	kg.
,,	175 l	,,	,,	10·5	,,
,,	225 l	,,	,,	9·6	,,
,,	270 l	,,	,,	8·5	,,
,,	290 l	,,	,,	7·0	,,
,,	300 l	,,	,,	6·2	,,

The writer's experience does not confirm these figures exactly, but they are near enough to serve as a guide.

Now, in some countries the standard quality of carbide is 290 litres to the kilogramme (say 4·65 ft. per lb.), and as a matter of fact the carbide often does not yield more than 280 litres. Other factories on the other hand which are jealous of their reputation for quality, will not send out carbide yielding less than 310 litres (say nearly 5 ft. per lb.). Here again is a difference of nearly 7 per cent. in the standard of comparison.

The writer, therefore, takes as basis raw carbide giving 300 to 310 litres per kg. Measuring the power on the high-tension side of the transformers, a production of 6 kilos (13·2 lbs.) per kilowatt-day (24 hrs.) of raw carbide giving 300 litres per kg is to be considered satisfactory and will often not even be reached as an average over a whole year.

With smaller furnaces than 600 h.p. it will be found very difficult to reach this figure; the production will be about 10 per cent. less.

A higher figure than 6 Kg can be reached in large furnaces by observing certain precautions and following certain designs, but it is safe to say that in many carbide factories the figure of 6 Kg is not even reached as the average output over a considerable period, say, six months.

This figure of 6 Kg per K.W.-day means a production of 1,980 Kg, say, 1·98 tonne per year of 330 days, equivalent to 1·48 tonne per English, or 1·46 tonne per Continental h.p. year, or 2,190 Kg, say, 2·19 tonne per year of 365 days, equivalent to 1·64 tonne per English, or 1·62 tonne per Continental h.p.-year.

Many carbide factories pride themselves upon turning out more than 6 Kg per K.W.-day, but if the total tonnes turned out by them in the course of a year be taken and this figure be divided by the actual horse-power available, it will usually be found that the figure is nearer 1 tonne per horse-power-year than the 1½ mentioned above, even after due allowance has been made for the difference in weight between raw and packed carbide due to dust.

The writer would like to go even farther and call attention to the woeful discrepancy between the figures given by most carbide factories as to the power they have available for carbide manufacture and the quantity of carbide actually produced by them. A comparison between the power they say they have available and the quantity of carbide which the writer *knows* they manufacture would actually seem to prove the average production of saleable carbide is much less than 1 tonne per h.p.-year. The explanation is in all probability that the quantity of power available is nearly always exaggerated.

Having dealt with the practical side as regards production, let us turn to the theoretical side and endeavour to find out what improvement can still be effected in the production. Unfortunately, we stumble at once upon an very important obstacle, preventing any accurate calculation, viz., our ignorance of the temperature of formation of calcium carbide in a commercial furnace; indeed, it must be pointed out at once that the temperature of formation will be always varying according to the variation in the quantities of impurities present in the raw materials.

Originally, the temperature of formation was believed to be round about 3,500°C. (6,332°F.). It has, however, gradually become clear that this figure is considerably too high, even for commercial practice.

Many calculations have been made to show the theoretical heat balance of a carbide furnace. We take the first one from Prof. Vogel's "Acetylene." The calculation is, we believe, based upon that made by Gin.

Heat required to form lime (CaO) ...	145,000 cal.
,, ,, ,, carbon monoxide	26,100 ,,
,, ,, ,, calcium carbide	3,900 ,,
Temp. of formation of calcium carbide	3,000°C.
Specific heat of lime at 3,000°C. ...	0·266
Molecular ,, ,, ,, ...	14·4
Specific ,, carbon ,, ...	0·535
Atomic ,, ,, ,, ...	6·420

The formula being $CaO + 3C = CaC_2 + 2CO$, the following heat will be required:—

To raise the one molecule of lime (CaO) to 3,000°C, there will be required $14{\cdot}4 \times 3{,}000 = 43{,}200$ cal.; to raise the three atoms of carbon to 3,000°C. there will be required $6{\cdot}42 \times 3 \times 3{,}000 = 57{,}780$ cal. to dissociate the molecule of lime 115,000 cal.; total calories required, 215,980, equal to (per molecule), 249·87 watt hours, equal to 3,900 Kilowatt-hours per Kg of carbide.

Even if this calculation were correct—and it ignores the heat given off in the formation of CO, heat which, according to some experts, serves the useful purpose of pre-heating the raw material—it is of little value as a guide to what can be done in commercial working, because it is based upon the use of lime and fuel of 100 per cent. purity.

The following calculations, made by an engineer in the writer's service, gets nearer to working conditions:—

$$\underset{\underbrace{40+16}_{56}}{CaO} + \underset{\underbrace{3\times12}_{36}}{3C} = \underset{\underbrace{40+24}_{64}}{CaC_2} + \underset{\underbrace{12+16}_{28}}{CO.}$$

Carbide, as now made by a first-class factory, yields 310 litres per Kg (4·95 ft. per lb.) and contains therefore 89 per cent. of pure carbide and 11 per cent. of impurities, and a metric ton of commercial carbide will contain 890 Kg of pure carbide.

To produce the 890 Kg of pure carbide in a metric ton, basing on lime of 96 per cent. purity and coke with 6 per cent. of ash, the following will be theoretically the quantities of raw materials required per metric ton of carbide:—

$$\text{lime}: \frac{56}{64}\times\frac{890\ \text{Kg}}{0{\cdot}96}=811\ \text{Kg.}$$

$$\text{coke}: \frac{36}{64}\times\frac{890\ \text{Kg}}{0{\cdot}96}=521\ \text{Kg.}$$

$$\text{Total}\quad \text{Kg}\ \underline{\overline{1{,}332}}$$

Assuming, for the sake of simplicity, that the impurities behave in the same way as the lime and coke respectively, we get the following:—

811 Kg of lime contain $\frac{811}{56}=14{\cdot}482$ Kg molecules.	
CaO requires 131,500 calories for its dissociation, so that for the dissociation of 14·482 molecules there will be required 131500 × 14·482 ...	1,904,383 cal.
The specific heat of lime at 3,000° is 0·2571 (?), so that to raise 811 Kg to that temperature we require 811 × 3,000 × 0·2571	625,524 „
The specific heat of coke (carbon) at 3,000° is 0·535, so that we require 521 × 3,000 × 0·535	836,205 „
Total	3,366,112 cal.

Total	3,366,112 cal.
From this has to be deducted the heat set up by the formation of CO, at the rate of 29,000 Cal. for, say, 14·2 molecules	411,800 ,,
Heat required	2,954,312 cal.

Disregarding the small (?) amount of heat set up by the formation of the carbide and taking the K.W.-hour as being equal to 833 (?) Calories, the electric energy required will be $\frac{29}{833}$=3,495 K.W.-hours, equal to a production of 6·86 Kg per K.W.-day.

The above reasoning does not seem to us to be correct Even if it were faultless as a theoretical exercise, it condemns itself from the point of view of actual facts, because the production of 6·86 Kg has been already reached in actual practice—in other words, the furnace in question had an efficiency of 100 per cent.—an absurdity.

In order to work out a heat-balance, it is first of all necessary to ascertain reasonably accurately what the approximate chemical equation is for the formation of calcium carbide under commercial conditions.

The experiments for this purpose referred to below were carried out with an open furnace of 1,000 kw and a larger closed one.

For the purpose of the equation we shall deal chiefly with the open furnace, the experiments having proved somewhat easier to realise with this type of furnace.

The carbide produced was of 87·6% purity; in other words, in each 1,000 kg of the commercial product there were 876 kg of true carbide.

To produce this carbide the following raw materials were used:—

1. 150 kg of coke.
2. 450 ,, anthracite.
3. 950 ,, lime.
4. 22 ,, electrode carbon

Total 1572 kg.

The analyses of these materials worked out as follows:—

	C	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Coke	91·80	3·25	0·60	2·72	0·175	0·071
Anthracite	92·30	0·855	0·28	1·06	0·130	0·065
Lime	0·60	0·77	0·18	0·25	94·80	0·65
Electrode	96·00	1·8	1·60	0·20	?	?

	S	P	H	O	N
Coke	0·89	0·032	0·41	0·01	0·12
Anthracite	0·77	0·010	2·21	1·42	0·81
Lime	0·21	0·01	0·40	1·80	?
Electrode	?	?	?	?	?

A part of the C and the H in the coke and the anthracite exists really in the shape of hydro-carbons, but the quantity is so small that we have increased the quantities of the elements themselves proportionately.

Recalculated in kilos for the quantities of raw materials used, the preceding analyses show:—

	C	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Coke	137·70	4·88	0·90	4·08	0·26	0·10
Anthracite ...	415·35	3·85	1·26	4·77	0·58	0·29
Lime	5·70	7·32	1·71	2·38	900·60	6·18
Electrode ...	21·12	0·40	0·35	0·04	—	0·08
Total Kilos ..	579·87	16·45	4·22	11·27	901·44	6·65

	S	P	H	O	N
Coke	1·33	0·05	0·62	0·015	0·18
Anthracite	3·47	0·04	9·95	6·40	3·65
Lime	2·00	0·10	3·80	17·10	
Electrode	—	—	—	—	—
Total Kilos	6·80	0·19	14·37	23·515	3·83

The above totals add up to 1568·605 kg, the difference of 13·40 kg being of course due to small losses in the analyses.

Calculated to weights of the elements, we get the following:—

	C	Si	Fe	Al	Ca	Mg
Kilos	579·87	7·68	2·95	5·97	643·89	3·99

	S	P	H	O	N
Kilos	**6·80**	**0·19**	**14·37**	**299·06**	**3·83**

We have now to ascertain what the above 1568·6 kg of raw material produce; in other words, to work out the right-hand side of the equation in order to see if we can account for everything used.

We know that the furnace produces :—

(*a*) Calcium carbide;
(*b*) Gas;
(*c*) Dust contained in the gas;
(*d*) Slag removed from the furnace;
(*e*) Slag remaining in the furnace.

The carbide produced during this experiment analysed per 1,000 kg as follows :—

CARBIDE,

Carbide (CaC_2)	—867·50 kg	(542·2 kg Ca + 325·3 kg C)
C	10·20 „	(10·2 kg C)
SiO_2	11·98 „	(6·4 kg O + 5·6 kg Si)
CaO	97·10 „	(69·4 kg Ca + 27·7 kg O)
Fe_2O_3	2·60 „	(0·8 kg O + 1·8 kg Fe)
Al_2O_3	4·50 „	(2·1 kg O + 2·4 kg Al)
MgO	1·52 „	(0·6 kg O + 0·9 kg Mg)
S	0·50 „	
P	0·016 „	
N	2·01 „	

Total—997·926 kg = 611·6 kg Ca + 335·5 kg C + 37·6 kg O + 5·6 kg Si + 1·8 kg Fe + 2·4 kg Al + 0·9 kg Mg + 0·50 kg S + 0·016 kg P + 2·01 kg N.

Gas.—Very great difficulty was experienced in obtaining reliable samples of the gases from an open furnace. Even when two samples were taken at the same time, at spots close together, considerable variations were found.

The following analysis was made for the writer by a Norwegian chemist, but appears to be doubtful:—

CO_2	4·1	per cent.	(by volume)
CO	1·3	„	„
O	16·6	„	„
N	78	„	„

The compounds of Si, Mg, etc., are dealt with further on under the heading "dust."

Samples were also captured from a furnace kept as carefully closed as possible. Even these were found to vary considerably. We again give a typical analysis:—

CO_2	3·12	per cent.	(by weight)
CO	82·29	„	„
CH_4	0·83	„	„
N	10·40	„	„
H	1·44	„	„
SO_2	1·92	„	„

The writer feels some diffidence about the SO_2 figure shown in this analysis, as it does not seem to be confirmed by other analyses. It may be useful to remark here that in blast furnace practice the sulphur in the fuel, when it is partly present in the form of iron pyrites (as is usually the case), has been shown partly to pass into the gases as sulphur vapour (which usually burns to SO_2 on the surface of the charge in an open furnace), and partly to be oxidised in the furnace itself to SO_2 and as such to appear in the gases, while the rest, according to Richards, passes along with the organic sulphur, either into the slag or the pig-iron. Sulphur passing into the slag is usually found in the shape of CaS, the form in which, according to Caro, it is also usually found in calcium carbide.

Another analysis of the gases from a closed furnace, kindly given to the writer by another factory, reads as follows:—

CO_2	...	—	(by volume).
CO	...	65·8	,,
H_2	...	30·9	,,
CH_4	...	2·0	,,
N_2	...	1·3	,,

If we base upon the first of the two analyses of the gases from a closed furnace, we find that the following escapes in the form of gas:—

CO_2 ... 20·06 kg = (5·47 kg C + 14·59 kg O)
CO ... 529·12 ,, = (226·76 kg C + 302·35 kg O)
CH_4 ... 5·34 ,, = (4·00 kg C + 1·34kg H).
N ... 66·87 ,, =
H ... 9·26 ,, = (9·26 kg H).
SO_2 ... 12·34 ,, = (6·17 kg O + 6·17 kg S).

Total 643·00 kg = 236·23kg C + 323·11 kg O + 10·6 kg H + 6·17 kg S + 66·87 kg N.

The above weights are equivalent to the following volumes:—

CO_2 ... 20·06 ÷ 1·98 = 10·1 m^3 = by volume 1·7%.
CO ... 529·12 ÷ 1·26 = 420·0 ,, ,, 70·3 ,,
CH_4 ... 5·34 ÷ 0·72 = 7·4 ,, ,, 1·2 ,,
N ... 66·87 ÷ 1·26 = 53·1 ,, ,, 8·9 ,,
H ... 9·26 ÷ 0·09 = 103·0 ,, ,, 17·2 ,,
SO_2 ... 12·34 ÷ 2·88 = 4·3 ,, ,, 0·7 ,,

597·9 m^3

Of course, the 597·9 m³ of gas shown above is in no way the volume produced in an open furnace, in which most of the CO is burnt to CO_2, and, in addition, the great volume of N accompanying the oxygen taken from the air has to be reckoned with.

DUST.—Many experiments were made in order to determine as accurately as possible the loss in dust from the furnace. The samples of gas, both from the open and closed furnaces, varied, however, enormously as regards the weight of dust contained per m³. With one and the same furnace, the dust figure varied according to the place where the test-tube was inserted, and also according to whether fresh raw material was coming down into the furnace, the furnace was being tapped or poked, etc.

The nearest average that could be arrived at showed that the loss in dust was 4·98 kg, or, say, for ease of calculation, 5 kg for each tonne of carbide produced in an open furnace, using low voltage. In a furnace using high voltage, the loss was considerably higher.

The analysis of dust is as follows :—

$CaCO_3$	36·36	per cent.
CaO	36·34	,,
Al_2O	8·00	,,
Fe_2O_3	6·00	,,
SiO_2	4·00	,,
$CaSO_4$	1·60	,,
C	7·00	,,
MgO	traces.	
Moisture	0·40	per cent.
Total ...	99·70	

Totalling up the various weights we get in kilos (it should be noted that in order to avoid as much as possible discrepancies through the uncertainty as to how much O and N is derived from the air above the furnace, the analysis below of the gas is based upon that from a closed furnace):—

In the—	Ca	C	Si	Fe	Al	Mg
Carbide	611·6	335·5	5·60	1·80	2·40	0·90
Gas	—	236·6	—	—	—	—
Dust	2·05	0·57	0·09	0·21	0·21	—
Total	613·65	572·30	5·69	2·01	2·61	0·90
In raw materials	643·89	579·87	7·68	2·95	5·97	3·99

In the—	S	P	H	O	N
Carbide	0·50	0·016	—	37·6	2·01
Gas	6·17	traces	10·6	323·11	66·87
Dust	0·02	—	—	1·81	—
Total	6·69	0·016	10·6	362·52	68·88
In raw materials	6·80	0·19	14·37	299·06	3·83

Of course, the above figures are—and cannot well be anything else than—approximate, since not only the raw materials vary very much (a pocket of quartz or iron pyrites, for instance, will entirely change the percentage of silica or iron oxide), but every carbide manufacturer knows only too well how one and the same tapping of carbide will yield different analyses in different parts of it.

On the whole, however, the left and right-hand sides of the equation equalise themselves fairly well. The excess of oxygen and nitrogen shown in the products from the furnace (the right-hand side) is, without doubt, due to the introduction of air, although it must be confessed that the two elements do not seem to balance each other very well.

Any discrepancy in the iron figures is easily understandable, as the ferro-silicon in the carbide is not equally distributed throughout the mass, but runs into pockets. It is therefore very difficult to get a sample of carbide containing a fair average of iron compounds.

There still remains the slag to be accounted for, but this is an almost impossible task, because very little slag is tapped out of the furnace in the course of the regular production of carbide. It is usually removed by special operations, and it is therefore impossible to say what particular part of the slag has been produced by a particular part of the raw materials. Another difficulty is the fact that a part of the impurities in the raw materials undoubtedly fuses to the sides and bottom of the furnaces and may therefore not be removed until, for instance, the end of a run of a year or more.

The analysis of some very troublesome slag which accumulated in a furnace may be of interest: Carborundum, 60·6 per cent.; Calcium Carbide, 16 per cent.; Silica, 17 per cent.; Metallic Iron, 1·61 per cent.; Alumina, 0·76 per cent.; Lime, 1·10 per cent ; Magnesia, 2·26 per cent.; Phosphorus, trace. This furnace had been using coke containing about 8½ per cent. of ash (about one-half of which was silica). The lime was also fairly high in silica.

Although we have now got the quantities of the elements in the carbide, gas and dust to balance very approximately with those in our raw materials, it may be desirable to go a step farther and ascertain as completely as possible into what compounds these elements group themselves.

According to various authorities, the following impurities are usually found in carbide:—

Nitrogen	0·2 to 0·31% (Moissan)
Carbon	0·5 ,, 7· ,, (Vogel)
Lime	0·4 ,, 12· ,, (Vogel)
Silicon Carbide ...	0·01 ,, 0·6 ,,
Ferro-Silicon ...	0·2 ,, 3·2 ,,
Calcium Silicide ...	small quantities
Aluminium sulphide	,, ,,
Calcium Sulphide ...	These sulphur compounds amount in total to 0·20 to 0·42%(Caro).
Gypsum	
Carbo-sulphide ...	
Magnesia Compounds...	traces to 1·4%

It would take infinitely too long to endeavour to work out the quantities of the above compounds on the right-hand side of the equation. It will suffice for our purpose if we put the commercial equation as follows (we again point out that, as regards the gaseous products in this equation, these are based, not upon the analysis of the gases from the closed furnace, as in the preceding page, but upon what would probably be found if the wasted carbon were burnt to CO and CO_2, in the proportions shown in the analysis of the gases from the open furnace, and the H were burnt to H_2O):—

Raw materials containing in Kilos:

C	...	580·			867·5	kg	CaC_2
SiO_2	...	16·5			10·2	„	C
Fe_2O_3	...	4·2		about	10·0	„	SiO_2
Al_2O_3	...	11·3		„	98·0	„	CaO
CaO	...	901·4					
MgO	...	6·6		„	135·0	„	CO
S	...	6·8	produce	„	660·0	„	CO_2
P	...	0·2		„	1370·0	„	N
H	...	14·4				„	
O	...	23·5		„	132·0	„	Water Vapour
N	...	3·8		„	33·0	„	

of the various compounds mentioned on the preceding page.

Of course, on the left-hand side the elements are really found combined in many respects in a different way to that shown by the analyses. The sulphur and iron in the coal are, for instance, as already stated, usually found in the shape of iron pyrites.

The writer is of opinion that for the formation of calcium carbide, in a commercial furnace, an average temperature of about 2,400°C. is required. Basing on this temperature, and on the raw materials dealt with in the immediately preceding pages, the electric energy required to produce carbide of 86·75% purity would be about 2,350 kw.-hours per 1,000 kg. This would be equivalent to a production in a furnace of 100°/$_0$ efficiency (*i.e.*, a furnace without any heat or equivalent losses) of 10·2 per kw.-day. As this furnace only produced 6 kg there was a heat loss of $\frac{4\cdot2}{10\cdot2}$, say, 41·2%.

In order to see as much as possible where this heat loss lies, we shall try to analyse it in a subsequent chapter.

CHAPTER XX.

HEAT LOSSES IN FURNACE.

These heat losses may be divided as follows :—

1. Through ohmic resistance in the electrodes, and heat carried away from the furnace through the electrodes ;
2. Through ohmic resistance in the busbars and cables, or the equivalent of these ;
3. Through conduction and radiation through the walls of the furnace and through the top and bottom of the furnace;
4. Through the removal of heat from the furnace each time carbide is tapped out.

All the following calculations are based upon the use of a furnace carrying 1,000 kw, measured at the transformer terminals on the low tension side. The amperage was approximately 30,000.

HEAT LOSSES THROUGH ELECTRODES.

According to Hering, the heat losses through the electrodes, where there is no lateral loss (in other words, where the electrode is completely immersed in the raw material), are equal to the sum of the loss by heat conduction alone, and approximately half the Joulean loss.

In a carbide furnace, having, for instance, an electrode 6 ft. (1·80 m) in length, of which, say, only 1 ft. (30 cm) is immersed in the mixture, the Joulean loss will naturally be greater. This loss will diminish as the electrode gradually burns away, so that when the holder touches the mixture, the Joulean loss will be comparatively small. In the following calculations the loss of three-fourths of the Joulean heat is assumed, and the average length of the electrodes is taken as one-half of the electrode when new. It will be noticed that the Joulean heat (*a*) is almost the same as the conductivity heat (*b*) and (*c*), so that the electrodes comply with the law laid down by Hering for securing the minimum flow of heat from the furnace.

(*a*) The average Joulean heat was calculated to be 52·6 kw., three-fourths of which amounts to	39·4 kw.
(*b*) The average heat conductivity loss was calculated to be	36·6 kw.
(*c*) The average contact loss (subsequently greatly reduced) was found to be ...	21·0 kw.
Total loss ...	97 kw.

Checking these calculations over by means of the heat units carried away by the cooling water, the following figures were obtained (mean of 8 measurements) quantity of water per minute, 66 litres; average difference in temperature, 18·5°C.

The heat units carried away were therefore 66 × 18·5 = 1,221 Kg-Cal., equivalent (on the basis of 1 Kg-Cal. per minute = 69·77 watts) to 85·2 kw.

The two results thus agree very well, for the difference is probably accounted for by the fact that the holder is only partly water cooled, and the metal below the cooled portion is known to give off a considerable volume of heat. In our total heat losses, the electrodes will therefore be debited with a loss of 97 kw.

It may easily appear that, although it is difficult to reduce materially the heat losses through the upper electrodes, it should be an easy matter to construct the bottom in such a manner that no water-cooling is required, and to prevent heat losses through conduction by surrounding the bottom electrode with poor heat conductors. This has been tried in many instances, but the result has not been found particularly successful.

The reason for this is simple—it is once more the fact that the action of the electric energy is extremely local and, with or without water-cooling, the raw material arrives at the fusion zone at about the same temperature. The effect of water-cooling is, therefore, in the writer's opinion, chiefly to reduce the loss through conduction and resistance, not to remove heat from the zone of fusion.

A pretty clear proof of this is the fact that as the upper electrode of a furnace gets shorter, the production will usually be found to increase rather than to decrease, although the water-cooled head will be 1 to 1½ metres (say 40 to 60 inches) nearer the zone of fusion, when the carbons are nearly consumed, than it was when the carbons were new, so that the head requires considerably more water to cool it. This seems to show that so little useful heat is removed from the zone of fusion by the water that the decrease in the ohmic resistance results in a higher production.

Here are some figures showing how the shortening (through consumption of the carbon) of an upper electrode actually results in an increase in production although more energy was being carried away by the water :—

(*a*)	Average production in the first three days after changing electrodes	301
(*b*)	Average production in the last three days before changing electrodes	311
	Average heat units carried away by the cooling water during period (*a*)	49·6
	Average heat units carried away by the cooling water during period (*b*)	87·6

While the energy carried away by the water used to cool the upper electrode may not be useful energy—in other words, may be practically equivalent to a part of the heat resulting from the combustion of a part of the charge, which heat would be wasted in any event—the case is somewhat different as regards the heat units carried away by the water-cooling in a furnace having a bottom electrode. It cannot be proved that this heat is heat which would otherwise be wasted. It is also equally difficult to prove the reverse. As far, however, as our experiments go, there is no appreciable difference in production if a furnace with a bottom electrode is run first with water-cooling and then without. In this particular instance it may be well that the extra energy removed by the water-cooling was compensated for by reduced ohmic loss in the bottom electrode. The latter being made of metal, it is evident that the more the temperature is kept down, the lower the ohmic loss will be.

OHMIC LOSS IN SECONDARY CONDUCTORS.

In all electric furnace plants there must necessarily be a fairly considerable loss through ohmic resistance, and it is consequently the aim of the furnace designer to reduce this loss as much as possible by shortening the secondary conductors. With the tendency to increase the size of modern furnaces, this resistance loss tends to grow in greater proportion, inasmuch as it becomes necessary in large furnaces to arrange the busbars and cables in a different manner, partly to get them out of the way, partly in order to improve the power-factor.

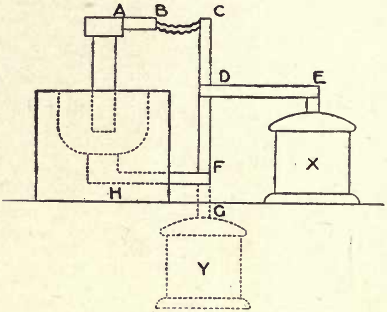


Fig. 34.

The most favourable case for furnaces with a bottom electrode will probably be when the transformers are placed in a pit just under the furnace and the conductors carried in a single loop up the back of the furnace, as shown by the dotted lines (position Y) in Fig. 34. Even in a case like this, it will be hardly possible to make the lengths A B C D F G and F H less than 8 metres (say, 26·2 feet), of which we will say 6·5 metres (21·3 feet) is busbar and 1·5 metre (4·9 feet) is cable.

As the length F G will be a double thickness o conductor, the total length of busbar is taken as being equivalent to 7 metres (say, 23 feet) of single conductor.

A section of 1 square inch per 1,000 amps. for the busbars (150 amps. per cm^2) and 1 square inch per 500 amps. (75 amps. per cm^2) for the cables is reckoned on, that being the standard usually adopted. The average temperature is taken at 100°C. (*i.e.*, the parts C D F G are assumed to be at an average temperature of 60° and the parts F H, A C at 140°C.).

The ohmic resistance of hard-drawn copper at 100°C. is taken at ·00000226 standard ohms per centimetre cube.

The conductors will, on above basis, have a section of 30 sq. in. (say, 194 cm^2) for the busbars and of 60 sq. in. (say, 388 cm^2) for the cables.

The ohmic loss (basing on the formula $\frac{C^2RL}{a}$) will therefore be:—

(*a*) In the busbars;

$$\frac{30{,}000 \times 30{,}000 \times \cdot 00000226 \times 700}{194 \times 1000} = 7 \cdot 34 \text{ kw.}$$

(*b*) In the cables:

$$\frac{30{,}000 \times 30{,}000 \times \cdot 00000226 \times 150}{388 \times 1000} = 0 \cdot 78 \text{ kw.}$$

Total ... 8·12 kw.

In the opinion of many authorities the loss is considerably greater than that given above. Measurements were stated to have been made in one case which showed the loss to be 28·2 kw. for a furnace of 1,000 kw.

To this loss through resistance in the bars and cables themselves must be added the contact losses. Even if the various lengths of busbars be welded together, for instance, by the oxy-acetylene process, two or three non-permanent joints must necessarily be left, even if these are only for the purpose of changing the electrodes.

The resistance at these contacts will vary enormously according to the way they are made and the care taken to keep them in good condition. It is only a short time ago that a case was brought to the writer's attention where the busbars melted through the very high temperature set up by resistance at a bad joint.

Measurements taken on a furnace of 1,000 kw. which had been in use for four years without the busbars being disconnected or the bottom carbons removed, showed that the total contact resistance was approximately 5·2 kw.

For furnaces working with no bottom electrode, it is evident that quite a different arrangement of the busbars will be desirable. Where floor space behind the furnaces is valuable, the transformers will usually be constructed with the secondary terminals at the bottom, in order to allow the transformers to be placed on the first floor of the building, *i.e.*, on a floor about level with the top of the busbars.

In the case of very large furnaces it is, of course, necessary to bring the busbars to the sides of the electrodes and balance them—if we may so express it—and they must be arranged in a certain manner in order to improve the power-factor. This means that there will be a considerably greater length of busbars and, in some cases, also of cables, than in the case of the simple single-phase furnace shown in the last illustration, and there will be consequently an increase in both the ohmic loss per unit of section and in the self-induction.

As regards the ohmic loss for three-phase furnaces, with three upper electrodes, the total loss will, as a general rule, be more than for the simple single-phase furnace, owing to the much greater length usually necessary. It would, indeed, be considerably less if an equal amount of metal were used in the conductors, inasmuch as the amperes will be usually only half as much. in consequence of the higher voltage, and, in addition, no return conductors are required. It is, however, customary, in order to economise in the capital expenditure, to make the section of the conductors of such an area that the resistance loss is approximately the same per metre of length of bar as for the single-phase furnace.

We have already mentioned the matter of the loss caused by the contact between the carbons and the holders, and it will be of interest to give some data respecting this.

According to C. A. Hansen, the contact losses between brass and graphite, with loads of 15,000 and 20,000 amp. are 19·30 and 24 kw respectively.

These contact losses were, however, for a contact made by squeezing a flat carbon between flat metal holders by means of bolts. Experience has shown that such a form of contact invariably sets up a high resistance, especially when the graphite paste usually smeared between the contact surfaces has been in use some time. In the old days this form of contact caused constant trouble through burning.

Lately the contacts have been vastly improved and, judging by the quantity of heat carried away by the cooling water, it is safe to say that the above-mentioned figures can be greatly reduced, even for a contact carrying 50 amps. per sq. in., as used by the writer.

HEAT LOSSES THROUGH CONDUCTION AND RADIATION.

We will first of all deal with the loss through the four vertical walls of the furnace.

According to Hering, the loss due to conduction (the radiation from the furnace mouth is dealt with separately) from brick (of which most carbide furnaces are to-day constructed, the iron lagging having, as a rule, been dispensed with) to air at 20°C. is as follows:—

(*Metall. and Chem. Engineering* of January, 1912.)

0·097	watt	per cm^2	(0·63	watt	per sq. in.)	with brick at	90°.
0·14	,,	,,	(0·90	,,	,,)	,,	110°.
0·17	,,	,,	(1·11	,,	,,)	,,	130°.
0·22	,,	,,	(1·4	,,	,,)	,,	150°.
0·27	,,	,,	(1·7	,,	,,)	,,	170°.
0·32	,,	,,	(2·1	,,	,,)	,,	190°.
0·42	,,	,,	(2·7	,,	,,)	,,	220°.

Hering states further that a carefully constructed electric furnace should have a loss through the walls of not more than 10%. We give in Fig. 35 diagrams showing the actual temperatures of the walls of a 1,000 kw. furnace and will mention that these figures were not considered satisfactory, and were considerably improved upon later on. It will be seen that the average temperature of the corner squares was 143·4°C. and that of the central squares was 214·1°C., so that it will be fair to assume an average for the whole surface of 164·2°C. On the other hand, the air temperature in the furnace room at the time the readings were taken was found to be 22°C., so that the difference between wall temperature and air-temperature is about equivalent to a heat loss of 0·25 watt per cm^2. The area of the four walls of the furnace was 351,120 cm^2, so that the loss was $351{,}120 \times 0{\cdot}25$ watts equal to approximately 87·8 kw.

It may be stated here that this conduction loss is liable to increase hugely as the size of the furnace increases. In a furnace of 2,000 kw, with much thicker walls, it was found at first difficult to keep the wall temperature down to the figure ultimately obtained for the smaller furnace (of course, it is assumed that artificial cooling does not enter into consideration). According to Hering's figures, it would appear that if the wall temperature is doubled, the conduction loss increases approximately three times.

The foregoing figures do not include loss through the bottom of the furnace, it being extremely difficult to make a calculation for this, owing to the furnace not being raised from the ground, but seated upon a solid mass of excellent heat-insulating material. Tests were made as far as possible, and the writer is inclined to put the loss down at not more than half that through one of the walls, equivalent to, let us say, 12 kw.

It will be noticed from the diagrams of the temperatures that no figure is given for the furnace mouth or the surface immediately under it Again we quote the invaluable data of Hering, who states that a crucible at a bright red heat may radiate and conduct 12 to 15 kw. per sq. ft. of surface (·013 to ·016 kw. per cm^2).

As the mouthpiece of a carbide furnace is usually at a white heat, it will, perhaps, be not too much to reckon upon the higher figure of 15 kw., and as the furnace mouth had an area of $1\frac{1}{2}$ sq. ft., we put the loss at 25 kw., this including the area under the mouth. It should be mentioned that certain steps were subsequently taken to reduce this loss, but as the test was obtained when the mouthpiece was radiating at full power, we include the full loss. The total loss therefore through the walls was 87·8 + 25 kw. = 112·8 kw., if we include the furnace mouthpiece, or 124·8 (say, 12½%) of the electric load, if we include the bottom also.

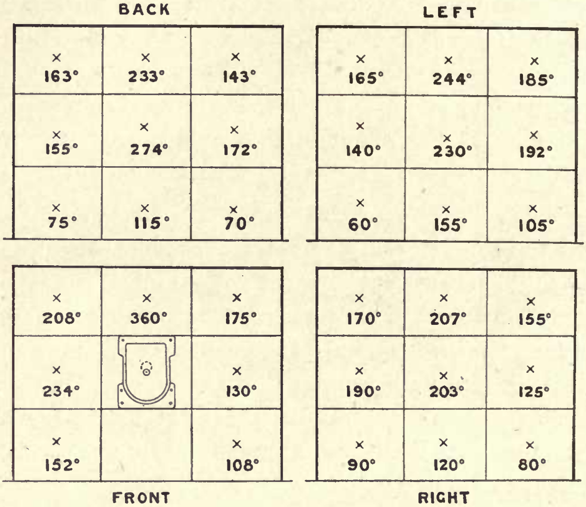

BACK
163°
233°
143°
155°
274°
172°
75°
115°
70°
LEFT
165°
244°
185°
140°
230°
192°
60°
155°
105°
208°
360°
175°
234°
130°
152°
108°
FRONT
170°
207°
155°
190°
203°
125°
90°
120°
80°
RIGHT

Fig. 35.

Heat Loss through the Top of an Open Furnace.

The next loss we have to consider is that through the open top of the furnace.

The average temperature on the surface of the raw materials was found by dividing the top up into imaginary squares and ascertaining the temperature of each. The maximum temperature was, of course, found near the electrode, but it is remarkable that even at a point where the furnace was "blowing," the temperature found was 1,190°C., while in other cases 1,150°C. was not exceeded.

The heat loss through the top of an open furnace may be divided into two parts:—

(*a*) The heat carried away in the waste gases (which burn round the upper electrode);

(*b*) The heat escaping through the remaining part of the surface of the raw material, where no visible combustion takes place.

In order to calculate loss (*a*) it was, of course, first necessary to ascertain the temperature of the escaping gases.

The temperature was found to vary considerably, but as a fair average a temperature of 1,000°C. may be taken. Basing upon this temperature, there will be approximately the following quantity of heat carried away in the waste gases (we say approximately, because of the variations found in the analyses of the gases):—

$CO_2 - 660$ Kg $\times [(0{\cdot}19 \times 1000)$
$+ (0{\cdot}00011 \times 1000^2)] = 198{,}000$ Cal.

$CO - 135$ Kg
$N - 1370$ Kg

1505 Kg $\times [(0{\cdot}2405 \times 1000)$
$+ (0{\cdot}0000214 \times 1000^2)] = 349{,}159$ „

$H_2O - 132$ Kg $\times [(0{\cdot}34 \times 1000)$
$+ (0{\cdot}00015 \times 1000^2)] = 64{,}680$ „

656,839 Cal.

This is the amount of heat lost per tonne of carbide. As 250 Kg are produced per hour, the loss per hour will be 164,210 Cal.

Equal, at 859 Cal. = 1 kw, to 191·2 kw.

As regards loss (*b*), the average temperature on that part of the surface of the raw materials, where no combustion takes place, was found to be approximately 400°C.

It is extremely difficult to calculate the heat loss in this part of the furnace, because it manifestly depends upon the quantity of air which passes over this heated surface. We therefore fall back on Hering, who says that with a heat loss of ½ kw. per sq. ft., the material is too hot to touch, while at dull red heat a metal loses 7 to 11 kw. per square foot.

We therefore assume a loss of 5 kw per sq. foot, for 16 square feet, say ...	80 kw.
Add loss previously calculated	191·2 „
Total loss through top of furnace ...	272·2 „

Lastly, we have to calculate the heat carried away in the block of carbide.

As is well known, the temperature of the carbide falls with great rapidity, and we therefore take the temperature at which the molten carbide leaves the furnace to be 2100° C.

The specific heat of carbide has not been determined accurately. Vogel reckons it out to be 0·325 at 2000° C. We think this figure will probably be considerably changed, when accurate observations are made later on. Meanwhile, we base upon 0·33 for 2100° C., so that the heat loss works out as follows per 250 kg (quantity produced per hour):

250 kg × 0·33 × 2100 =	173,250 Cal.
@ 859 Cal. = 1 kw.	220 kw.

Summing up we get therefore :

(*a*)	Loss through the electrodes	97 kw
(*b*)	„ „ „ busbars and cables ...	8·1 „
(*c*)	„ „ „ contacts	5·2 „
(*d*)	„ „ „ walls	87·8 „
(*e*)	„ „ „ bottom...	12 „
(*f*)	„ „ „ mouthpiece	25 „
(*g*)	„ „ „ top	271·2 „
(*h*)	„ „ „ tapped out carbide ...	202 „
	Total of heat losses	708·3 „

The input of the furnace is :

(*a*)	Electric energy		1,000 kw.
(*b*)	244 kg of carbon, burnt to waste, taken at its full value as if burnt to CO_2 $(244 \times 8100) =$	1,976,400 Cal.	
(*c*)	14·4 kg of H burnt to waste $(14{\cdot}4 \times 29030) =$	418,032 „	
	Thus per tonne of carbide ... ... =	2,394,432 Cal.	
	Equal to per hour (¼)	598,608 „ =	697 kw.
	Total input		1,697 kw.

The heat loss was therefore $\frac{708{\cdot}3}{1697} = 41{\cdot}7\%$, so that the efficiency of the furnace was 58·3%. As the furnace produced 6 kg of carbide per 24 kw—24 hours, the production, if there were no heat losses, would be $\frac{6 \times 100}{58{\cdot}3} =$ 10·3 kg, a figure which agrees very well with our calcuation of the Calories required to make carbide.

This calculation is of course very approximate. So many factors are unfortunately only approximately known.

Similar calculations have been carried out for a closed furnace. The author hopes to publish them later on.

On first blush it might appear that a very large saving could at once be effected by not allowing the waste gases to burn on the surface, and that, if they were saved, they might advantageously be used, for instance, for burning the lime.

This matter has engaged the attention of most carbide engineers. It is all a question of final result. If the production of carbide per unit of energy is reduced by saving the CO, this saving might easily result in a loss in the final balance.

CHAPTER XXI.

POWER FACTOR.

For the benefit of the beginner, we may mention that, in an alternating current circuit, the voltmeters and ammeters do not show, except in very exceptional cases, the true power which is passing through the circuit; in other words, if the volts are multiplied by the amperes, the resulting figure does not give the watts passing.

In a circuit containing electric furnaces, the actual power passing is always less than the apparent power. The factor (cosine ø) by which the actual product of the ammeter and voltmeter readings must be multiplied in order to obtain the real load passing, is known as the power-factor.

In most carbide factories there has been a constant endeavour to increase the electric load per furnace, or per hearth, in the case of multi-phase furnaces.

As a rule, each increase of the load carried has led to a more unfavourable or lower power-factor, and in some cases the factor has been too low to allow of the most economical use of the plant.

A low power-factor is troublesome for many reasons. In the first place it limits the output of the power-station generators by demagnetising the field magnets and causing heating of the windings. In one case known to the writer through an arbitration suit he was compelled to take part in, the whole of the windings of one generator had to be renewed. Many generators have their output limited by the capacity of their field magnets. If we regard the capacity of the field magnet only, we find that its output at a power-factor=1 is four times as great as at a power-factor=0·8.

It was soon found that in furnaces using alternating current the power-factor went down extremely rapidly, as soon as a certain load was reached, and that by increasing the current beyond a certain maximum, no increase in the actual load on the surface was brought about.

Until recently it has been held that the power-factor should theoretically be favourably influenced by reduction of the periodicity and by increase of the voltage, and unfavourably by increase in the amperes.

Unfortunately, the literature respecting the causes which influence the power-factor of a circuit containing an electric furnace or furnaces is of the most meagre description. With the exception of a paper read at the Seventh International Calcium Carbide and Acetylene Congress at Rome, in 1913, by Messrs. L. Lombardi and O. Scarpa, very little information of any real interest has appeared in print.

Many years ago, the writer noticed that when the furnaces began to reach a load which made the question of the power-factor a serious one, the generally accepted theory, already referred to above, does not apply invariably to an electric furnace.

Very careful measurements were made with instruments of precision, and it was found that with absolutely steady voltage the power-factor did not always go down when the amperes went up, or go up when the amperes went down, so that it was clear that the working of the furnace itself, or what takes place between the upper and lower electrode, influenced the power-factor.

At one factory belonging to the writer's group, a Westinghouse power-factor meter was installed and the same phenomenon was observed. Later on the writer caused measurements to be taken again with precision instruments by a well-known expert in electric measurements from a Norwegian University. Some of the large number of measurements taken are given below :—

Primary Voltage.	*Amperes.*	*Power-factor.*
5200	210	0·92
,,	230	0·91
,,	230	0·92
,,	240	0·90
,,	250	0·92
,,	250	0·92
,,	250	0·93
,,	260	0·91
5300	220	0·92
,,	230	0·90
,,	230	0·92
,,	230	0·91
,,	240	0·91
,,	240	0·92
,,	250	0·92
,,	250	0·91
5500	200	0·92
,,	210	0·93
,,	210	0·90
,,	210	0·94
,,	220	0·92
,,	230	0·93
,,	240	0·90
,,	240	0·91

It will be noticed, to take one instance, that in one case the power-factor was found to be the same with a current of 230 amperes as with a current of 260 amperes at the same pressure of 5200 volts.

In the paper referred to above, Messrs. Lombardi and Scarpa give the results of experiments carried out by them with a carbide furnace installed in the electrochemical laboratory in the University of Naples. The figures obtained by these gentlemen are infinitely more remarkable than those obtained by the writer.

We give below the figures published by them, from which it will be seen that they actually found that by reducing the current below a certain limit the power factor rapidly became worse as the current fell:—

Secondary Voltage.	*Amperes.*	*Power Factor.*
40	293	0·96
,,	252	0·92
,,	198	0·87
,,	155	0 84
,,	100	0·80

The experimenters came to the conclusion that phenomena in the furnace itself had the result of modifying the phase and the form of the current. One of these phenomena they thought could be due to the electrolytic decomposition of the carbide, by which an electromotive force of polarisation could be produced capable of changing the form of the curve.

They were, however, of opinion that this electromotive force could not exceed a small fraction of one volt, so that the phase-displacement caused by it would be negligible. On the other hand, they believed that the influence which could be exercised on the power-factor by periodical variations in the internal resistance of the furnace, due to variable phenomena of ionisation, were of much more importance, and that if certain precautions were not taken in the working of the furnace, the curves of current and of potential could be largely changed.

In other words, they are of opinion that the low power-factor observed by many experimenters is due to imperfect regulation of the furnaces.

Whether it is due to the furnaces with which the writer has had to do with having always been regulated very carefully, or to other causes, he must frankly confess that the variations due to the working of the furnace itself have usually moved within about the comparatively narrow limits given in his figures on page 167. His experience is that, with the exception of these fluctuations, the power-factor undoubtedly tends to become less favourable as the amperage increases or the voltage decreases.

The diagrams on pages 171 and 173, which are based upon actual measurements taken with great care in the year 1909, during a period of three weeks, seem to prove that this is the fact. For certain reasons the writer is not able to give the voltage in the case of the second diagram shown, but it was what is usually considered a low one.

On the other hand, it may be said that the design of the furnace—and we include in the furnace, in this instance, the low tension busbars and cables—plays a very important role as regards the power factor.

A furnace which has a power factor of, say, 0·85 with a load of only 1,000 kw if the furnace and secondary circuit are badly arranged, can have its load raised to about 1,300 kw by a more suitable arrangement.

There are various devices, which cannot be called a part of the furnace or busbars proper, which can be adopted for improving the power-factor. Without these outside appliances, the limit for a low pressure furnace working at 50 periods p.s. appears to be about 1,000 kw with ordinary arrangement of busbars, etc., and 1,300 to 1,500 kw with a special arrangement of busbars and furnace. The power factor is assumed not to be satisfactory unless it is above 0·80.

In a high-pressure series furnace a load can be obtained of about 2,000 to 2,750 kw, according to the system adopted. This is roughly the load possible per hearth for a three-phase (three upper-electrode) furnace, working with a pressure of 85 to 100 volts.

Experiments which have been carried on lately appear to shew that these figures can be improved upon, but this whole question of power-factor will, without doubt, receive in the future the attention which the constant striving to increase the size of electric furnaces makes imperative.

It is, however, quite possible that in the near future we may see a return to the use of direct current for large electric furnaces for making calcium carbide and similar electric-chemicals. Aluminium engineers are showing the way to use direct current in large units.

As regards the voltage, it can be assumed that in the present state of our industry, the maximum pressure used is about 100 v. and the minimum 29 v. We have already seen that the former pressure causes a higher consumption of electrodes and of raw materials than the lower one, without showing any appreciable increase in the production. It does, however, enable larger furnace units to be used, owing to the more favourable power-

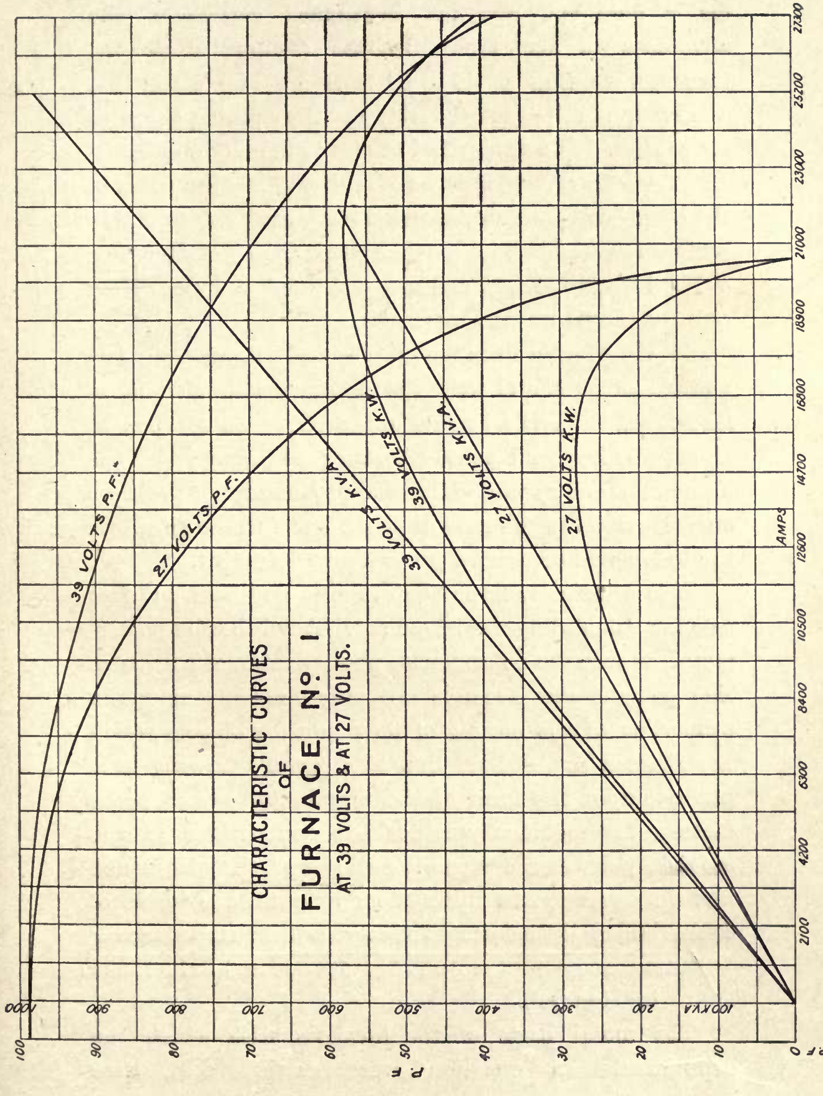

CHARACTERISTIC CURVES
OF
FURNACE No. I
AT 39 VOLTS & AT 27 VOLTS.
39 VOLTS P.F.
27 VOLTS P.F.
39 VOLTS K.V.A.
39 VOLTS K.W.
27 VOLTS K.V.A.
27 VOLTS K.W.
AMPS
2100
4200
6300
8400
10500
12600
14700
16800
18900
21000
23100
25200
27300
100 KVA
200
300
400
500
600
700
800
900
1000
P.F
0
10
20
30
40
50
60
70
80
90
100

Fig. 36.

factor obtained, and, as mentioned elsewhere, the advocates of the large 3-phase (3-upper-electrodes) furnaces, working at 80 to 90 volts pressure, claim that a reduction in the capital outlay and the running expenses for repairs, depreciation and labour is thereby obtained.

It is, however, open to doubt whether the users of the large, high-pressure furnaces have been able to obtain a more favourable final balance sheet than the advocates of the low-pressure (one upper and one lower electrode), or other single-phase types.

It will be seen from diagram Fig. 36 that with the low voltage of 39 v. and with the ordinary arrangement of leads, etc., the critical point appeared to be reached at about 580 kw, and that thereafter an increase of the amperes simply resulted in the production of wattless current, while in the case of the other furnace (Fig. 37) the load could be carried up to about 1,460 kw.

It is practically impossible to give any hard and fast rule for calculating in advance what will be the power-factor, or even the approximate power-factor, of a furnace. The power-factor depends not only upon the magnetic properties of the circuit of neighbouring objects which are affected by the field due to a current flowing in it but also upon the form of the circuit and several other factors, for instance whether the connections in the secondary circuit are properly made, or properly tightened up; in other words upon the ohmic resistance, as of course is clear if the formula be correct that: Impedance = $\sqrt{\text{Resistance}^2 + (2 \times 3{\cdot}1416 \times \text{periods and inductance in Henrys}^2)}$.

The metal parts of the furnaces with which the experiments in question were carried out, were constructed practically entirely of copper, the iron bands surrounding the furnace being broken by long copper connections, where they crossed the "loop." There was also no other iron in close enough proximity to affect the power-factor, this being clearly proved by removing and replacing various iron parts in the neighbourhood of the furnace. The presence or absence of these iron parts did not seem to affect the power-factor.

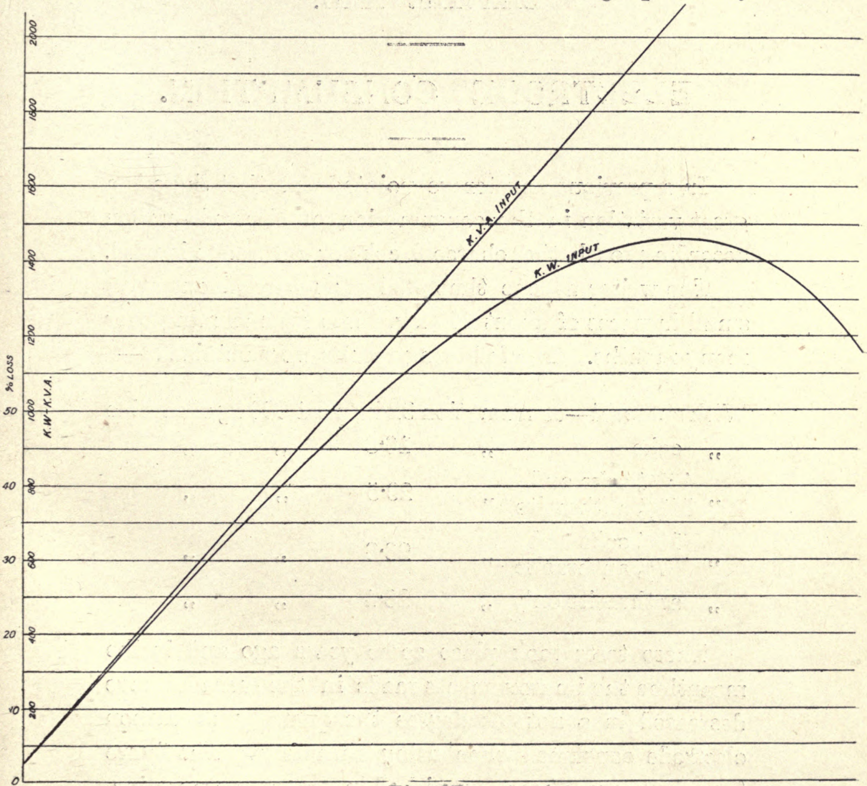


Fig. 37.

CHAPTER XXII.

ELECTRODE CONSUMPTION.

In a previous chapter we pointed out that there is a great variation in the consumption of electrode-carbon according to whether charcoal, coke or anthracite is used.

The writer at one time had tests carried out with small furnaces of about 250 kw, these tests running over many months. The following results were obtained :—

With	charcoal—	consumption	92 kg	per 1,000 kg	of carbide
,,	coke	,,	16·8	,,	,,
"	45½% coke and 54½% anthracite	"	20·5	,,	,,
"	13% coke and 87% anthracite	"	26·8	,,	,,
,,	anthracite only	,,	26·4	,,	,,

These tests took place some years ago and in the meantime the improvements made in the furnaces have decreased in a notable degree the quantity of carbon electrode consumed when using anthracite. The figure for coke has not been diminished in the same proportion, but it is still safe to say that using coke of good quality, the consumption of electrode will be approximately one-third less than the consumption with anthracite.

The higher consumption with anthracite is probably due to the greater percentage of "volatile" than in coke.

From the analyses previously given it will be seen that Welsh anthracite contains 5·5 to 7·5% of "volatile." This "volatile" consists of oxygen, hydrogen and nitrogen. According to information kindly furnished to the writer by one of the most expert coal analysts in South Wales, Welsh anthracite contains 2 to 3% of O; 2·5 to 3·5% of H; and 0·7 to 1% of N.

Other authorities put the oxygen in Welsh anthracite at a higher figure than the hydrogen; Percy for instance gives 4·75 parts of hydrogen and 5·28 parts of oxygen to each 100 parts of carbon. On the other hand, well-burnt metallurgical coke contains usually at most ½% of oxygen or hydrogen.

In any case, it is remarkable that the increased consumption of electrode carbon, when anthracite is used, corresponds so closely with the weight of carbon required to neutralise the extra oxygen in the anthracite, as compared with that in coke.

If we assume that anthracite contains 2½% more oxygen than coke and that 600 kilos of the former are required to make 1,000 kg of carbide, it is clear that there will be 15 kg more of oxygen to be got rid of when anthracite is used. This 15 kg will require 12 kg of carbon to form CO. It will be noticed that the table of consumption given above shows that about 10 kg more carbon electrode was consumed with anthracite than with coke.

The table referred to seems again to support this theory (viz. that extra oxygen in the coke or coal means extra consumption of the carbon electrodes), if we turn to the figures for charcoal. We may mention here that some writers attribute the reduction in the consumption of carbon electrode, when coke is used, to the latter having a greater volume than anthracite. They say that the greater volume of the coke allows less of the lime to come in contact with the electrode and consequently the latter is not eaten away to so great an extent by the oxygen in the lime.

If this latter view be correct, then charcoal should give a much more satisfactory consumption of electrode, even than coke, inasmuch as its volumetric weight is much lower than that of coke and, in addition, a much greater weight is required per ton of carbide produced.

The tables, however, show that the consumption of electrode carbon, when charcoal was used, reached the enormous figure of 9·2% (92 kg of carbon per tonne of carbide.)

This figure was not obtained as the result of a day or two of experimental working; the figure is the average for three months of working, with a load of 1,000 kw. Immediately coke was substituted for charcoal, using the same furnaces and the same description of lime, the consumption of electrode carbon decreased enormously.

The coke used for the above mentioned three months of working was burnt in the usual crude way followed by country wood-cutters and charcoal-burners. It consequently contained a very high figure of "volatile," consisting on the average of 2% of hydrogen and nearly 15% of oxygen (the analyses all varied considerably, probably through the samples coming from various parts of the stack).

According to Violette, the ratio of carbon to "volatile" varies enormously according to the temperature at which the wood has been "burnt," the following figures giving some of the results found by him:—

Temperature of Burning.	ANALYSIS OF THE CHARCOAL.		
	Carbon.	Hydrogen.	Oxygen.
280°C.	71·6	4·7	22·1
350	76·7	4·1	18·4
432	81·6	1·9	15·2
1030	81·9	2·3	14·1
1250	88·1	1·4	9·2

According to other text books, the usual temperature at which charcoal is burnt is 400°C. and at this temperature the coke contains: 81·5% of carbon, 4·1% of hydrogen, and 14·1% of oxygen.

It will thus be seen that, with charcoal "burnt" in the ordinary way, at least 14% of oxygen must be reckoned with.

The trouble through the high figure of oxygen, in the case of the factory mentioned above, was immensely aggravated by the enormous quantity of charcoal used per ton of carbide, the consumption being on the average 1,250 kg per 1,000 kg of carbide, or nearly twice as much as in the case of coke.

Lately a case came under the writer's notice confirming this view as to the cause of high electrode consumption, the President of an American carbide factory having informed him that their electrode consumption having increased very considerably, enquiries were made and it was found that the coke suppliers had been delivering under-burnt coke, with a large percentage of "volatile." Arrangements were made to obtain coke burnt—or to be more correct, baked—to the same degree as formerly, whereupon the electrode consumption at once sank to the previous figures.

Without doubt the record for low carbon consumption is obtained with the Horry type of furnace used by the Union Carbide Co. of Niagara Falls, the consumption per 1,000 kg of carbide being stated to be 4 to 6 lbs. (kilos?) The electrodes used are, however, of Acheson graphite, costing nearly four times as much as ordinary baked ones. The result in any case, however, can only be considered highly satisfactory from the economical point of view.

It is of course easy in a furnace of the Horry type to imbed the parts of the carbon which are not actually doing work, in a thick coating of non-oxidising material, thereby completely protecting them from the corrosive action of oxygen or carbon-dioxide.

CHAPTER XXIII.

PACKING.

Under this heading we propose to deal simply with the cost of manufacturing the types of drums most generally used.

It may be stated that practically all carbide to-day is packed in one or other of the following types:—

(*a*) Drums of lead-coated (terne) plate having a disc of metal soldered over the opening in the top (Fig. 29, page 71).

(*b*) The same type of drum as (*a*), but with a friction lid and thin plate soldered over the lid (Fig. 30, page 71).

(*c*) The American drum with a screw top, made of so-called "black plate" and having a disc or cover of thinner metal over it in order to prevent the screw lid being tampered with during carriage (Fig. 28, page 70).

(*d*) The so-called "returnable" drum proper, made of heavy sheet metal and usually having a lid fastened by bolts or screws.

(*e*) Drums of the types mentioned in (*a*), (*b*), (*c*), having in addition an outer covering or cask of wood, the drum and wood covering constituting the so-called "export" packing.

These five varieties are those employed by the vast majority of carbide makers to-day. Some of the Italian factories have made large use of a square box of thin tinned plate, the tin box being enclosed in a rather fragile box, but unfortunate experience has shown that this type of packing is eminently unsuited for the rough treatment that carbide is usually favoured with during carriage on land and water; indeed, in the latter case it has often happened that the vessel has discharged the wood-packing first, by the simple and expeditious process of flinging it from the vessel upon the quay, while the tin boxes follow on later in all their naked charm, if, indeed, in this case variety (of appearance) may be said to be charming.

Dealing first of all with the so-called "non-returnable" drums, (*a*), (*b*), and (*c*), it may be remarked that the regulations in nearly all countries call for the following minimum thickness of plate :—

(1) 0·6 mm. (0·0236 inch) for drums holding more than 50 kg (about 1 cwt.), or 0·4 mm. (0·01575 inch), if holding 50 kg or below, if the drums are intended for transport over seas and provided the drums are enclosed in stout wood over-casks or cases ;

(2) 0·4 mm. for uncased drums holding up to 100 kg (about 2 cwt.) intended for distribution by rail only on the Continent, or by river carriage. This thickness of plate is, in the writer's opinion, too little for drums holding 100 kg, unless cased with wood.

(3) 0·6 mm. for uncased wooden drums holding not more than 50 kg intended for sea traffic. Attempts have been made to use uncased

drums holding 100 kg and of 0·6 mm. thickness for this kind of trade, but the results have been unsatisfactory; most of the shipping lines have consequently set their faces against them, although in some cases they are freely accepted, for instance, for Holland, Portugal, etc.

The cost of making the different descriptions of drums naturally varies in every factory, not only because one factory will be, for instance, equipped with a more up-to-date and efficient plant than its neighbour, but because the carbide varies in volume according to the process employed; in other words, 100 kg of carbide made at one factory will require a larger drum than the same weight made at another factory, where the carbide is more dense.

Taking a factory producing hard tapped carbide, the drums will be found to have about the following sizes and weights (the dimensions and weights do not include wood over-casks or cases and are for drums of 0·6 mm. thickness):—

Holding 100 kg: Height, 23¾ in. (600 mm.); diameter, 16¾ in. (425 mm.); nett cubic contents, about 4,810 cub. in. (78,100 cm^3.); weight, about 12½ lbs. (5·65 kg).

Holding 50 kg: Height, 23¾ in. (600 mm.); diameter, 12 in. (305 mm.); nett cubic contents, about 2,440 in. (39,980 cm^3); weight, about 8¾ lbs (3·96 kg).

The wood over-cask or case adds about 1½ in. (38 mm.) to the height and about 1¼ in (32 mm.) to the diameter, and nearly 150% to the weight, a wood-cased drum of 100 kg (2 cwt.) weighing therefore 25 to 30 lbs. (11·13 to 13·5 kg).

The cost of the various types of drums (without any allowance for Customs duty on the plates) works out approximately as follows for the drum holding 50 kg, made of 0·6 mm. plate (these prices are, of course, based upon pre-war costs):—

Type (*a*).

	s.	*d.*
Terne plate (including weight of scrap), 8·8 lbs. (4·2 kg)	1	1
Labour (including soldering)		1
Solder		1
Supervision, wear and tear, and depreciation of machinery, interest, motive power, insurance, etc.		2
Cost per 50 kg drum (fr. 1·77)	1	5

Type (*b*).

The cost of this type is that for type (*a*), with the addition of the extra expenditures for making the lever-lid (friction lid) and the thin disc, which can be taken at about 1d. (10 cms.), making the total cost 1s. 6d. (fr. 1·88).

Type (*c*)

It may appear strange, but provided a full line of up-to-date machinery be used this type of drum, in spite of its screw top and extra lid, is cheaper to make than type (*a*). The reasons are that black plate is used, a much cheaper material, and there are no soldered joints, a very expensive item in the cost of type (*a*). Repeated tests made by the writer showed however that these drums, as usually made, are not air-tight, and special machinery was devised at his suggestion which not only strengthened the joints and made them tighter, but enabled a much more satisfactory lid to be made at less cost. The cost of the different items is:—

	d.
Plate (including scrap) 10·2 lbs. (4·6 kg) ...	11·0
Labour	0·8
Painting, (including paint)	1·0
Washer for the screw top	0·1
Supervision, wear and tear of plant, interest, depreciation, motive power, insurance, etc. ...	2·2
Patent royalties	0·5
Cost per 50 kg drum (fr. 1·63)	15·6d.
say	1/3½

Type (*d*).

The writer knows of no carbide factory which makes drums of this description. They are, as far as his experience goes, bought ready made and their cost varies from 5s. (fr. 6·25) to 7s. 6d. (fr. 9·40) each, according to their weight, construction of the lid, etc. Their weight varies from 20 to 28 lbs. (9 to 12¾ kg).

The prices for non-returnable drums just given may be considered too low if a strict separate account be kept for the drum-making shop as a separate entity, for it is evident that there is no separate allowance for profit, taxes, correspondence, and the host of little items which swell the cost of manufacturing most articles.

The actual cost can be, perhaps, judged more accurately by means of a quotation made by a very large English firm in 1913, the price quoted being 1s. 7d. for the 50 kg drum of type (*a*)

Type (*e*)

The cost of this type is, of course, that of types (*a*), (*b*), (*c*), with the addition of the outlay for the wood overcasks. The cost of the latter was, in 1913, about 9·1d. for the 50 kg (or 1 cwt.) and 12·1d. for the 100 kg (2 cwt.) drum, where the carbide factory bought wood scrap and worked it up in its own shops.

Lately, however, the cost of this wood packing has, like everything else, gone up enormously, and at the time of writing it is difficult to give definite figures of cost.

It should be pointed out that in consequence of the regulations of some of the shipping lines, it has become customary to make the edges of the wood staves of V shape, so that they dovetail into each other.

Of course, in a very large number of cases the carbide reaches the consumer in a totally different packing to that employed by the factories. This is especially the case where carbide for motor cars, cycles, portable lamps, etc., is concerned, the custom being to use for these purposes lever lid tins containing ½-lb. (or ¼ kg), 1 lb. (or ½ kg), 2 lbs. (or 1 kg), 4 lbs. (or 2 kg), and 7 lbs. (or 3 kg). For some purposes also tins of 10 lbs., 14 lbs. and 28 lbs. are used.

Hardly any of the carbide factories, however, pack carbide in tins holding less than 28 lbs. (12¾ kg); the packing in the smaller tins is usually left to the wholesaler or retailer.

CHAPTER XXIV.

TESTING OF THE CARBIDE AND QUALITY.

In most countries of the world calcium carbide is sold under the rules either of the British or German Acetylene Associations.

The rules until lately were practically identical, but for some time the British Acetylene Association has been considering the question of making additions, in consequence of a large quantity of carbide having been put upon the market, which, although satisfying the requirements as to gas-yield and maximum of phosphorus compounds, was found to cause over-heating in the generator.

The British rules are reproduced below :—

REGULATIONS AS TO QUALITY, SIZE, &c., OF CARBIDE OF CALCIUM.

1. The carbide shall be guaranteed by the seller to yield, when broken to standard size—*i.e.*, in lumps varying from 1 to 2½ inches or larger—not less than 4·8 cubic feet per lb., at a barometric pressure of 30 inches and temperature of 60 deg. Fahr. (15·55 deg. Centigrade).

Carbide yielding less than 4·8 cubic feet in the sizes given above shall be paid for in proportion to the gas yield, *i.e.*, the price to be paid shall bear the same relation to the contract price as the gas yield bears to 4·8 cubic feet per lb.

The actual gas yield shall be deemed to be the gas yield ascertained by the analyst, plus 5 per cent.

2. The customer shall have the right to refuse to take carbide yielding in the sizes mentioned above less than 4·2 cubic feet per lb., and it shall lie, in case of refusal and as from the date of the result of the analysis being made known to either party, at the risk and expense of the seller.

3. The carbide shall not contain higher figures of impurities than shall from time to time be fixed by the Association.

4. No guarantee shall be given for lots of less than 3 cwt., or for carbide crushed to smaller than the above sizes.

5. In case of dispute as to quality, either the buyer or the seller shall have the right to have one unopened drum per ton of carbide, or part of a ton, sent for examination to one of the analysts appointed by the Association, and the result of the examination shall be held to apply to the whole of the consignment to which the drum belonged.

6. A latitude of 5 per cent. shall be allowed for analysis; consequently differences of 5 per cent. above or below the yields mentioned in 1 and 2 shall not be taken into consideration.

7. Should the yield of gas be less than 4·8 cubic feet less 5 per cent., the carriage of the carbide to and from the place of analysis and the cost of the analysis shall be paid for by the seller Should the yield be 4·8 cubic feet or more, less 5 per cent. the carriage and

costs of analysis shall be borne by the buyer, who, in addition, shall pay an increase of price for the carbide proportionate to the gas yield above 4·8 cubic feet plus 5 per cent.

8. Carbide of one-inch mesh and above shall not contain more than 5 per cent. of dust. Such dust to be defined as carbide capable of passing through a mesh of one-sixteenth of an inch.

9. The seller shall not be responsible for deterioration of quality caused by railway carriage in the United Kingdom, unless he has sold including carriage to the destination indicated by the buyer.

10. Carbide destined for export to countries outside Europe shall, in case the buyer desires to have it tested, be sampled at the port of shipment, and the guarantee shall cease after shipment. In all other cases the responsibility of the seller shall cease two months after the delivery of the carbide, unless his buyer shall have lodged a complaint within that period.

11. The analyst shall take a sample of not less than 1 lb. each from the top, centre, and bottom of the drum. The carbide shall be carefully broken up into small pieces, due care being taken to avoid exposure to the air as much as possible, carefully screened and tested for gas yield by decomposing it in water, previously thoroughly saturated by exposure to acetylene for a period of not less than 48 hours.

12. Carbide which, when properly decomposed, yields acetylene containing from all phosphorus compounds therein more than ·05 per cent. by volume of phosphoretted hydrogen, may be refused by the buyer, and any carbide found to contain more than this

figure, with a latitude of 0·1 per cent. for the analysis, shall lie at the risk and expense of the seller in the manner described in paragraph 2.

The rules mentioned in paragraph 7 shall apply as regards the carriage and costs of analysis; in other words, the buyer shall pay these costs if the figure is below 0·05 per per cent. plus 0·01 per cent., and the seller if the figure is 0·05 per cent. or over, plus 0·01 per cent.

The sampling shall take place in the manner prescribed in paragraphs 5 and 11, and the analytical examination shall be effected in the manner prescribed by the Association and obtainable upon application to the Secretary.

It may be taken that, as a rule, the carbide factories do not send out lump carbide which has not been tested to give an average of at least 305 litres per kg (4·9 ft. per lb.); many of them manufacture carbide testing fully 310 litres per kg (nearly 5 ft. per lb.)

These figures apply to carbide of about $\frac{3}{4}$-inch mesh and upwards, and the rules of the various Associations do not call even for the standard gas-yield of 300 litres (4·8 ft.) for smaller carbide.

It is well known that the smaller the size of lump the smaller the gas-yield per lb., the reason of course being that the smaller the lump, the larger is the area which is exposed to the air and consequently likely to be slaked by the moisture in the air.

Except where special precautions are taken to protect the smaller sizes from air-slaking, the following figures will show pretty fairly the average gas-yield from the various sizes of carbide:—

Size	50 to 80 mm.	(2 to $3\frac{1}{2}$ in.)	4·82 to 5·05 ft.	(300 to 315 l.)
,,	25 ,, 50 ,,	(1 ,, 2 in.)	4·65 ,, 4·82 ,,	(290 ,, 300 l.)
,,	15 ,, 25 ,,	($\frac{5}{8}$,, 1 in.)	4·48 ,, 4·82 ,,	(280 ,, 300 l.)
,,	7 ,, 15 ,,	($\frac{1}{4}$,, $\frac{5}{8}$ in.)	4·25 ,, 4·69 ,,	(265 ,, 294 l.)
,,	4 ,, 7 ,,	($\frac{1}{6}$,, $\frac{1}{4}$ in.)	4·15 ,, 4·57 ,,	(260 ,, 285 l.)
,,	2 ,, 4 ,,	($\frac{1}{12}$,, $\frac{1}{6}$ in.)	3·85 ,, 4·16 ,,	(240 ,, 260 l.)
,,	1 ,, 2 ,,	($\frac{1}{25}$,, $\frac{1}{12}$ in.)	3·2 ,, 4 ,,	(200 , 250 l.)

The dust below 1 mm. in size varies enormously in gas-yield; samples in some factories will only give about 100 litres (1·6 ft.), while other dust tested by the writer has yielded nearly 250 litres (4 ft.) As a rule the arrangements for crushing and screening have more to do with the gas-yield from dust than a little higher or lower quality of the carbide.

Many expedients have been resorted to in order to improve the gas-yield from granulated carbide by protecting it from air-slaking. One of the best of these is the use of graphite or blacklead for coating the pieces. This not only protects the carbide to a great extent from air-slaking, but slows the generation down somewhat, and, last, not least, improves its appearance.

Even many wholesale and retail dealers apparently find it difficult to realise that commercial carbide of, say 300 litres (4·8 ft.) gas-yield is not pure carbide, but, on the contrary, contains roughly 14 per cent. of impurities. The bulk of the impurities consists of unconverted lime, and, in consequence, is not noticed by the consumer. Should he, however, find a pound or two of ferro-silicon, or a few pieces of coke, or coked coal, in a drum, he usually hastens to pour forth his indignation. He does not know that a drum of commercial carbide containing, say, 50 kg (110 lbs.) nett, will consist of 94½ lbs. (86%) of pure carbide and no less than 15½ lbs. (14%) of impurities.

The following table shows the percentage of true carbide corresponding to various gas-yields:—

100% = 348·9 litres per kg = 5·589 cu. ft. per lb.
99 = 345·4 ,, ,, = 5·533 ,, ,,
98 = 341·9 ,, ,, = 5·477 ,, ,,
97 = 338·4 ,, ,, = 5·421 ,, ,,
96 = 334·9 ,, ,, = 5·365 ,, ,,
95 = 331·5 ,, ,, = 5·309 ,, ,,
94 = 328·0 ,, ,, = 5·253 ,, ,,
93 = 324·5 ,, ,, = 5·197 ,, ,,
92 = 321·0 ,, ,, = 5·142 ,, ,,
91 = 317·5 ,, ,, = 5·086 ,, ,,
90 = 314·0 ,, ,, = 5·030 ,, ,,
89 = 310·5 ,, ,, = 4·974 ,, ,,
88 = 307·0 ,, ,, = 4·918 ,, ,,
87 = 303·5 ,, ,, = 4·862 ,, ,,
86 = 300·0 ,, ,, = 4·806 ,, ,,
85 = 296·5 ,, ,, = 4·749 ,, ,,
84 = 293·0 ,, ,, = 4·693 ,, ,,
83 = 289·5 ,, ,, = 4·637 ,, ,,
82 = 286·0 ,, ,, = 4·581 ,, ,,
81 = 282·5 ,, ,, = 4·525 ,, ,,
80 = 279·0 ,, ,, = 4·469 ,, ,,
79 = 275·5 ,, ,, = 4·413 ,, ,,
78 = 272·0 ,, ,, = 4·357 ,, ,,

It is evident from what is said above that a carbide buyer would have no just cause of complaint, as far as gas-yield is concerned, if his drum of carbide contained 15½ lbs. of iron or coke, provided the gas-yield from the whole contents of the drum amounted to 528 cubic feet (4·8 × 110).

The writer dwells on this question of ferro-silicon, because it is such a fruitful cause of complaints, although in the writer's experience, as already pointed out elsewhere, high-grade carbide is usually rich in ferro-silicon.

All tests for gas-yield have to be reduced to a standard temperature and standard barometric pressure. It is often found particularly difficult to convince a carbide consumer that he cannot always expect a pound of carbide to give exactly the same volume of gas; he often marks off his gas-bell with paint-marks, each stripe indicating the height the bell should rise for each pound of carbide decomposed or gasified. On some frosty morning, when the temperature is low and the barometer is high, he finds that when he puts a pound of carbide in his generator the bell does not rise to the mark. He tries again, and again there is a shortage, and he at once writes to his supplier that the last carbide was so bad that he has had to use twice the usual quantity (it is always twice as much).

He overlooks the fact that as it gets colder, acetylene, like other gases, shrinks, and as the barometer goes up the pressure of the air increases and compresses a cubic foot of gas into a smaller space.

The writer has had to give this explanation so many hundreds of times that this must be his excuse for dwelling on these rather elementary points.

Few, however, even of the most enlightened trade buyers of carbide, realise, until they have seen a table, the enormous difference in the volume of gas a heavy storm can make. It will be seen from the table on page 193 that when the barometer is right down before the approach of a heavy storm, say at 720 mm. and the temperature is 15°C., the gas yield must be multiplied by 94·6 per cent. in order to obtain the true yield, while when the glass has gone up to set fair, say 770 mm., the yield must be multiplied by 101·3 per cent., a difference through barometric pressure alone of nearly 7 per cent. on the first figure. or say about a third of a cubic foot on the standard yield of 4·8 ft. per lb.

A still greater difference will be found between the volume of gas in heavy warm weather in summer, as before a thunderstorm (say with the barometer at 720 mm. (28·368 in.) and the thermometer at 30°C. (86°F.), and in bright frosty weather in winter, with the barometer at say 770 mm. (30·338 in.) and thermometer at freezing point. The yield has to be multiplied in the first case by 87·6 and in the latter case by 108·1 per cent., a difference of no less than 21½ per cent. One and the same quality of carbide, of which the corrected yield is 5 ft. per lb., will therefore show a difference in the volume of gas in thundery summer weather, as compared with that in frosty winter weather, of more than a cubic foot per lb.

Of course, it should be clearly understood that the gas-yield itself in both cases has the same value. If it were customary to weigh the gas, instead of to measure its volume, the weather would not make even an apparent difference.

In order to make allowance for the influence of the weather on the volume of the gas, the gas-yield actually found by means of the testing apparatus is corrected, so as to represent what that yield would have been if the barometer had stood at 760 mm. and the thermometer at 15°C. (almost exactly equivalent to the English standard of barometric pressure and 60°F.), and the barometer readings had also been corrected.

The following table gives the figures by which the ascertained gas-yield has to be multiplied in order to

BAROMETRIC PRESSURE IN MILLIMETRES.

Degrees Centigrade.	660	670	680	690	700	710	720	730	740	750	760	770	780
0	92,5	93,9	95,4	96,8	98,2	99,6	101,0	102,4	103,8	105,2	106,7	108,1	109,5
1	92,1	93,5	95,0	96,4	97,8	99,2	100,6	102,0	103,4	104,8	106,2	107,6	109,0
2	91,8	93,2	94,6	96,0	97,4	98,8	100,2	101,6	103,0	104,4	105,8	107,2	108,6
3	91,4	92,8	94,2	95,6	97,0	98,3	99,7	101,1	102,5	103,9	105,3	106,7	108,1
4	91,0	92,4	93,7	95,1	96,5	97,9	99,3	100,7	102,1	103,5	104,9	106,3	107,7
5	90,6	92,0	93,4	94,7	96,1	97,5	98,9	100,3	101,6	103,0	104,4	105,8	107,2
6	90,2	91,6	92,9	94,3	95,7	97,1	98,5	99,8	101,2	102,6	104,0	105,4	106,8
7	89,8	91,2	92,6	93,9	95,3	96,7	98,1	99,5	100,8	102,2	103,6	105,0	106,3
8	89,4	90,8	92,2	93,5	94,9	96,3	97,7	99,0	100,4	101,8	103,1	104,5	105,9
9	89,0	90,4	91,8	93,1	94,5	95,9	97,2	98,6	100,0	101,3	102,7	104,1	105,4
10	88,6	90,0	91,4	92,7	94,1	95,4	96,8	98,2	99,5	100,9	102,3	103,6	105,0
11	88,3	89,6	91,0	92,3	93,7	95,0	96,4	97,7	99,1	100,5	101,8	103,2	104,5
12	87,8	89,2	90,5	91,9	93,3	94,6	96,0	97,3	98,7	100,0	101,4	102,7	104,1
13	87,4	88,8	90,1	91,5	92,8	94,2	95,5	96,9	98,2	99,6	100,9	102 3	103.6
14	87,0	88,4	89,7	91.0	92,4	93,7	95,1	96,4	97,8	99,1	100 5	101,8	103,1
15	86,6	88,0	89,3	90,6	92,0	93,3	94,6	96,0	97,3	98,7	100,0	101,3	102,7
16	86,2	87,5	88,9	90,2	91,5	92,9	94.2	95,5	96,9	98,2	99.5	100,9	102,2
17	85,8	87,1	88,4	89,8	91,1	92,4	93,8	95,1	96,4	97,7	99,1	100,4	101,7
18	85,4	86,7	88,0	89,3	90,7	92,0	93,3	94,6	96,0	97,3	98,6	100,0	101,3
19	84,9	86,3	87,6	88,9	90,2	91,6	92,9	94,2	95,5	96,8	98,2	99,5	100,8
20	84,5	85,8	87,2	88,5	89,7	91,1	92,4	93,7	95,0	96,4	97,7	99,0	100,3
21	84,1	85,4	86,7	88,0	89,3	90,6	92,0	93,3	94,6	95,9	97,2	98,5	99,8
22	83,7	85,0	86,3	87,6	88,9	90,2	91,5	92,8	94,1	95,4	96,7	98,0	99,3
23	83,2	84,5	85,8	87,1	88,4	89,7	91,0	92,3	93,6	94,9	96,2	97,5	98,8
24	82,8	84,0	85,4	86,7	88,0	89,2	90,5	91,8	93,1	94,4	95,7	97,0	98,3
25	82,3	83,6	84,9	86,2	87,5	88,8	90,1	91,4	92,7	94,0	95,3	96,5	97,8
26	81,8	83,1	84,4	85,7	87,0	88,3	89,6	90,9	92,2	93,4	94,7	96,0	97,3
27	81,4	82,7	83,9	85,2	86,5	87,8	89,1	90,4	91,7	92,9	94,2	95,5	96,8
28	80,9	82,2	83,5	84,7	86,0	87,3	88,6	89,9	91,2	92,4	93,7	95,0	96,3
29	80,4	81,7	83,0	84,2	85,5	86,8	88,1	89,4	90,6	91,9	93,2	94,5	95,7
30	79,9	81,2	82,5	83,7	85,0	86,3	87,6	88,8	90,1	91,4	92,6	93,9	95,2

Fig. 38.

arrive at the true corrected yield. Thus, if the temperature is 25°C., the barometric pressure 720 mm., and the gas-yield 310 litres, the corrected yield will be $310 \times 90{\cdot}1 = 289{\cdot}3$ litres per kg.

As it is the carbon alone in the carbide which is the useful element for forming acetylene, the lime being merely the "carrier," it is clear that the greater the proportion of lime in the mixture, the lower the gas-yield will be.

It is, however, well for the embryo manufacturer to know that he cannot go beyond a certain percentage of carbon in his mixture without the gas-yield suffering; in other words, if the carbide manufacturer goes beyond a certain point each ounce of additional coke or anthracite will reduce the quality of the carbide instead of improving it.

Many years ago Keller called attention to this interesting point by publishing the diagram reproduced in fig. 39.

This diagram shows also the very interesting fact that it is possible to make the raw material too rich in carbon, and that directly the latter exceeds 75 kg per 100 kg of lime the gas-yield begins to sink.

The diagram also shows another interesting fact, well-known to carbide manufacturers—viz., that as the percentage of lime in the mixture increases, the production per unit of electricity also increases, until, with 20 kg of carbon to 100 kg of lime, a production of no less than 11·9 kg (26·2 lbs.) per kilowatt-24 hours can be obtained—only unfortunately this carbide produces only 115 litres of acetylene per kg (1·84 ft. per lb.).

Another point shown by this diagram is that the standard yield of 300 litres per kilo. appears not to be

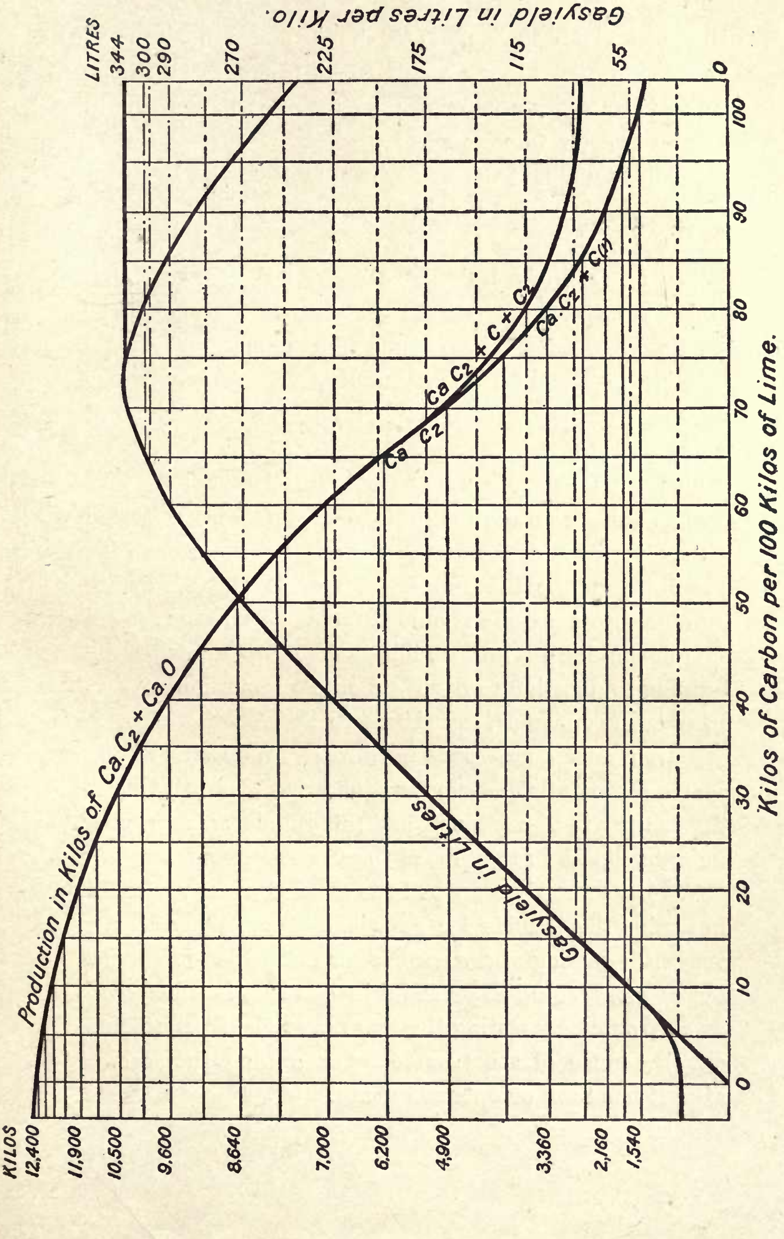

Gasyield in Litres per Kilo.
LITRES
344
300
290
270
225
175
115
55
0
KILOS
12,400
11,900
10,500
9,600
8,640
7,000
6,200
4,900
3,360
2,160
1,540
0
10
20
30
40
50
60
70
80
90
100
Production in Kilos of Ca.C2 + Ca.O
Gasyield in Litres
Ca C2
Ca C2 + C + C2
Ca.C2 + C(1)
Kilos of Carbon per 100 Kilos of Lime.

Fig. 39.

the most advantageous one for the carbide manufacturer; in other words, a lower yield per kg would result in one unit of electricity producing a weight of carbide giving in total a larger volume of gas.

This is undoubtedly the case, and this was the consideration which led to 290 litres per kg being adopted as the standard in some countries.

In cases, however, where a heavy freight, and sometimes a heavy duty based upon weight, had also to be paid, it was naturally soon found to be much more advantageous to supply a better quality, and ultimately the standard of 300 litres per kg was adopted as a kind of compromise.

The usual way of testing carbide in a factory is to take two samples from each tapping, one sample being tested either immediately, or, if taken during the night shifts, the first thing next morning. Where there is sufficient storage accommodation some factories seal up the second sample and keep it for a sufficient time to allow of the tapping in question to have got into circulation and to have been consumed, say six months.

Even this short period, however, necessitates the accumulation of so enormous a quantity of small tins, if the factory is of any size, that this rule is, we fear, now more honoured in the breach than in the observance.

We have already described the method usually adopted in testing the carbide for gas-yield. As a general rule, very little testing of the carbide for impurities is carried out at most factories, on the principle that it is better to avoid trouble, by testing the raw materials, than to find out the cause of the trouble by examining the carbide after it has been complained about.

At some time or other every carbide manufacturer will get his due share of complaints, whether merited or unmerited, and it will be well therefore for him to be fully posted as to the nature of what he may have to investigate.

The most common causes of complaint are nowadays, in their order of number, probably the following :—

(*a*) brown sludge, poor light and unusually large consumption;

(*b*) low gas-yield;

(*c*) haze.

Complaint (*a*) is nearly always due to "quick" carbide—*i.e.*, carbide which gives off its gas extremely rapidly. In such cases a much higher local temperature is set up than the acetylene can stand, with the result that the gas is polymerised; in other words, partly decomposed, or changed into other compounds.

An extreme illustration of what happens can be seen in the backyard of any carbide factory which throws away its dust.

When it begins to rain the generation of gas from this dust is so rapid that the temperature set up is sufficiently high to ignite the gas spontaneously, and very often little pops and crackling will be heard.

The same process goes on—but naturally in a much milder degree—when very "quick" carbide is used in a generator which feeds comparatively little water to the carbide. The carbide decomposes so rapidly that the water, or surrounding carbide or sludge, is not able to carry the heat away sufficiently quickly to prevent a high local temperature being set up.

Lewes ("Acetylene," page 400) states that in two cases examined by him the temperature of generation caused decomposition to such an extent that, in addition probably to the heavier hydrocarbons left behind in the sludge, the gas contained only 69·7 and 70% of acetylene respectively, the composition of the gas being as follows:

	Sample 1.		Sample 2.
Acetylene...	70·0 per cent.	...	69·7 per cent.
Methane ...	11·3 ,,	...	11·4 ,,
Hydrogen...	18·7 ,,	...	18·9 ,,

As hydrogen is a practically non-luminous gas and methane has a considerably lower illuminating value than acetylene, any considerable percentage of these gases will at once explain the complaints about poor light and also the higher comsumption of carbide. Lewes indeed remarks that the result of the overheating in the above cases was to reduce the illuminating value of the gas from 240 candles to 146, a reduction therefore of nearly 40 per cent.

The brown, or even black, sludge is of course due to the same cause. The writer has seen porous, lava-like carbide, which in a generator specially made for the purpose of glass gave off brown fumes; the whole of the sludge was of a dark brown colour.

While certain types of acetylene generators will always cause overheating at some time or other, it is evident that it is not in the interest of the acetylene and carbide industries that carbide should be put on the market, except in the rare case of accident, which is liable to cause excessive overheating in any reasonably good type of apparatus.

Ordinary methods of ascertaining the maximum temperature are, in the writer's experience, of little value for testing carbide rapidly for liability to cause overheating. Very good rough results have been obtained by the use of the author's apparatus, designed for this purpose. This apparatus really records the calorific or thermic result obtained in a fixed period of time. An apparatus which determines the total quantity of heat given off by a sample of carbide, when completely decomposed, is of course valueless for the purpose in view, as it is evident that carbide of a given quality will generate the same number of calories, if completely decomposed, whether it be quick or slow.

For testing in this apparatus, a sample of 100 grammes of carbide is taken from various samples aggregating say 1 kg, crushed in a covered mortar and then screened through a sieve of $\frac{1}{4}$ inch (6mm) and over a sieve of $\frac{1}{8}$ inch (3mm). The sample is placed in a wire basket, which is at once lowered into the water in a glass vessel (which is of course filled with a measured volume of water), until the basket reaches a fixed depth in the water and the carbide is completely submerged.

The carbide is allowed to remain one minute in the water and then removed. The temperature of the water is of course taken before the carbide is immersed and immediately after the basket leaves the water and the difference in temperature, multiplied by the quantity of water, will of course give the heat units given off to the water. It is of course clear that this test is only a comparative one, but it is easy enough to ascertain what should be the maximum quantity of heat given off in a certain time, in order to be sure that the carbide is reasonably slow in generation.

It is, of course, evident that the carbide must not be allowed to stop sufficiently long in the water for complete decomposition of the whole sample to take place and that distilled water, or a water of known composition, should always be used, and if possible always have the same temperature before using.

Complaint (*b*). It may be thought that this complaint can only be due to low gas yield of the carbide itself, but this is not so. The writer has on more than one occasion seen the water blown out of the seal of a generator, accompanied of course by a considerable escape of gas, through the use of a carbide which was very rich in gas and excessively quick. Some countries have regulations enforcing the provision of a chimney or pipe for carrying off any overmake of gas, so that it almost looks as if such overmaking is of pretty frequent occurrence. In the writer's experience, however, substantial losses through this cause are comparatively rare and therefore in the overwhelming majority of cases, complaints about low gas yield—if found to be justified (which is *not* the case as a general rule)—must be set down to poor quality of the carbide, the remedy for which is obvious.

Complaint (c). Nowadays haze is due to practically one cause only, *viz.*, excess of phosphorus compounds in the carbide.

Cases of this kind have to-day become uncommon, for most carbide manufacturers know where to procure raw materials which will safeguard them, with very rare exceptions, against complaints of this nature. In addition, a number of excellent chemical purifiers are now procurable, which make it difficult for haze to become apparent in a room, even if the carbide should contain rather more phosphorus than the rules enjoin.

The author would, however, like to point out that no chemical, or other purifier will, as far as his experience goes, prevent trouble, if the quantity of phosphorus compounds in the carbide should be really excessive, especially if the carbide is liable to cause overheating through "quickness" in decomposing. Tests carried out, on commercial lines, with various types of purifiers and purifying materials, showed conclusively that under the conditions mentioned in the previous paragraph, the most efficient apparatus or material failed to remove the bulk of the phosphorus compounds, even if the charge of purifying material had been in use for a couple of days.

In connection with this question, the author would like to emphasise in the strongest possible manner how important it is for the acetylene lighting industry that the temperature of generation should be as low as possible. The higher the temperature, the more the acetylene will smell, the poorer the light will be, and the more trouble there will be with the burners.

It is a remarkable fact that if the carbide from one and the same drum be taken and used in three different ways, the results will vary enormously. If water be sprayed on the carbide, or water be fed to the carbide in insufficient quantity, the gas will smell atrociously.

If, on the other hand, small quantities of the carbide be plunged into a large quantity of water, the smell will be far less pronounced and the gas much more pure.

If, lastly, the carbide be crushed up small, then thoroughly coated or impregnated with materials which retard its decomposition and then pressed into cakes, the strong smell will be found to have almost disappeared from the gas; indeed the absence of trouble from smell, or from choking up the burners, will absolutely astound even experts who have handled acetylene for years.

The diminution of the smell is, of course, due to a large proportion of the phosphorus compounds remaining in the sludge, instead of passing into the gas.

Analysis of the gas will clearly prove this and will show that the higher the temperature in the generating chamber of an acetylene apparatus, the higher the percentage of impurities will be in the resulting gas.

From gas analyses made in the laboratories of the writer's factories and from others kindly carried out by Mr. Gatehouse, the able chemist to the British Acetylene Association, it would appear that one and the same batch of carbide will produce acetylene having approximately:

12 units of impurities in the case of drip apparatus;
5 ,, ,, ,, certain water-to-carbide generators of good design;
4 units of impurities in the case of carbide-to-water generators;
1 unit of impurities in the case of apparatus using certain cakes of prepared carbide.

The results of the experiments made in this direction showed so clearly the enormous increase in the impurities in the gas as the temperature of generation increases that the writer asked Mr. Gatehouse to make further tests on:—

1. Carbide crushed to ¼ inch mesh, which had not been treated;
2. The same carbide made up into cakes.

In order to make the results as conclusive as possible, a certain quantity of lump carbide was sampled out, containing a fairly high figure of phosphorus. This carbide was crushed down to ¼ inch mesh and then thoroughly mixed up. Half the quantity was then made up into cakes and the other half left untreated.

The report is so interesting in many ways that it is reproduced in full below :—

THE ANALYTICAL LABORATORY,
36, BROAD STREET, BATH,
November 18th, 1910.

I, the undersigned, Public Analyst, do hereby certify that having experimented with a sample of "Carbic" and Carbic apparatus to determine (1) candles per cubic foot of acetylene as compared with acetylene generated from carbide in the ordinary way. (2) The purity of the gas generated from "Carbic" as compared with the purity of the gas generated in the ordinary way. Received on the 11th day of November, 1910, from C. C. Wakefield & Co., 27, Cannon Street, London; I find the same to yield the following results under the conditions specified.

> Experiments made with Carbic were conducted in the Company's special Carbic generator with Carbic cakes weighing approximately 1½ lbs. each (650 to 655 grammes). The experiments with ordinary carbide were made in my experimental apparatus in which small portions of carbide are continuously treated with excess of water, quantity used about ½ lb. for each experiment.
>
> The ordinary carbide used produced 4·45 cub. feet acetylene per pound, containing ·057 per cent. of Phosphoretted Hydrogen which was not passed through a purifier, but only washed.

In determining the candle-power of the acetylene generated from these two samples, "Carbic" and ordinary, respectively, the conditions were maintained as nearly as possible the same in each case, the pressure varying from 3·25 to 3·6 inches of water. The burners used were "Bray 28-litres," practically 1 cub. foot per hour. The gas actually measured by meter was slightly less than this, namely, 26 litres per hour, or 29 litres in 66 minutes respectively, subject to slight variations during the photometric tests.

The candle-power was measured in two ways: (1) against standard candles which gave—

Purified carbide: 38·2 candles.

Ordinary carbide (unpurified): 36 candles to 35·5 candles.

(2) Against each other the burners being exchanged on the various gases this gave—

(1) Carbic: Ordinary 37·6; 34·4 exchange burners;

(2) Ordinary: Carbic 35; 37;

which shows the quality of the burners used. With respect to the purity of the gas generated, time only permitted taking the PH_3 content.

Carbic ·012 per cent of PH_3.

Ordinary ·057 per cent of PH_3 by volume.

The purifying material was placed in the purifier quite lightly, dropping into place by its own weight only.

Awaiting your further commands,

I am, Gentlemen, yours obediently,

J. W. GATEHOUSE.

It will be seen from this report that even when the ordinary carbide was decomposed in the most advantageous manner possible, (*i.e.*, by using an excess of water), the phosphorus figure rose to about 4½ times as much as was the case when the same carbide was used in the form of cakes.

Furthermore, the gas produced from the cakes proved to have a higher illuminating value than that from the untreated carbide.

The lower luminosity of the latter can of course only be attributed to the gas being adulterated with a higher percentage of less valuable gases than acetylene, the production of these gases being of course due to overheating.

It is equally clear that if there is such a marked difference between treated carbide and ordinary carbide, when the latter is decomposed under the most favourable conditions, the difference becomes more and more pronounced as the system of generation uses less and less water, and consequently more heat is set up.

The writer must plead, as his excuse for dwelling so much on this question, that, in his experience, practically the whole of the troubles that acetylene has had to fight against, as far as its actual use is concerned, arise from overheating during generation.

Probably nothing has done more to prejudice people against acetylene than *smell.* Smell is most undoubtedly due to overheating.

If any of my readers doubt this, I earnestly ask them to procure some cakes and test the matter for themselves. They will find that even if a purifier be not used, the smell from the gas is decreased in such a remarkable manner that when a burner is open in one corner of a room, it is difficult to detect the smell in the opposite corner.

In short therefore, the treating of the carbide at once practically gets over the trouble caused by an unpleasant smell.

Another great advantage, as far as lighting is concerned, is the beautiful white appearance of the flame. This whiteness, which practically never varies, shows at once to the expert that the gas is of high quality.

If we turn to the welding side of the question, here again we find great advantages when the gas is generated at as low a temperature as possible.

Pure acetylene will undoubtedly do more work per cubic foot than acetylene which has been overheated during the process of generation, and which consequently contains fairly high percentages of other gases.

The work, according to many oxy-acetylene experts, is also better; indeed some of the foreign experts go so far as to say that when a weld is porous, the porosity is as a rule to be attributed to the use of acetylene diluted with too high a percentages of other gases.

The writer has no financial or other interest in any particular form of carbide cake; his greatest interest is to see carbide used under the most favourable conditions possible, and he therefore ventures to express the hope that, at some distant date, it will be possible for all users of acetylene to obtain their carbide supplies in a suitable prepared form, without any undue augmentation of price.

He is of opinion that this question of the temperature of generation has not received the attention its enormous importance deserves.

Those generator makers, who are really enterprising and who have in consequence put generators on the market of which they have every reason to feel proud, have, as far as he can trace, never had their attention drawn up to the present to the fact that it is possible to make still greater improvements.

The writer, therefore, ventures to express the fervent hope that these remarks may lead them to rise to still greater heights.

TABLES.

1. Length.

$\frac{1}{8}$ inch = 3·175 millimetre.

$\frac{1}{16}$ inch = 1·5875 millimetre.

$\frac{1}{2}$,, = 12·7 ,,

1 ,, = 2·54 centimetres (25·4 millimetres).

1 foot = 30·4799 ,,

1 yard = 91·4399 ,, (0·914399 metre).

1 mile = 1·6093 kilometres.

1 millimetre (mm) = 0·039370113 inch.

1 centimetre (cm) = 0·39370113 ,,

1 metre (m) = 39·370113 inches,

1 kilometre (km) = 0·62137 mile.

2. Area.

1 square inch = 6·4516 sq. centimetres.

1 ,, foot = 929·03 sq. centimetres
= ·092903 sq. metre.

1 ,, yard = 0·836126 sq. metre.

1 acre = 0·40468 hectare.

1 sq. millimetre (mm^2) = 0·00155 sq. inch.

1 ,, centimetre (cm^2) = 0·155 ,,

1 ,, metre (m^2) = 10·7639 sq. feet.

1 hectare (10,000 m^2) = 2·4711 acres.

3. Volume.

1 cubic inch = 16·387 cubic centimetres.
1 ,, foot = 0·028317 cubic metre = 28·317 litres.
1 gallon (British) = 4·545963 litres = 0·1605 cub. ft.
1 cub. centimetre (cm^3) = 0·061 cubic inch.
1 ,, decimetre (dm^3) = 61·024 ,,
1 litre (l) (1,000 cm^3) = 1·7598 pints.
1 cub. metre (m^3) (1,000 litres) = 35·3148 cub. feet.
1 U.S.A. gallon = 0·8325 Imp. gallon = 231 cub. in.

4. Weight.

1 grain = 0·0648 gramme.
1 pennyweight = 1·5552 ,,
1 drachm = 1·772 ,,
1 ounce (437½ grains) = 28·350 ,,
1 ,, troy (480 grains) = 31·1035 ,,
1 ,, (apothecary) = 31·1035 ,,
1 lb. (16 oz. = 7,000 grains) = 0·4535924 kilogramme.
,, = 453·5924 grammes.
,, = 445,000 dynes.
1 cwt. (British = 112 lbs.) = 50.8 kilogrammes.
1 ton (,, = 2240 ,,) = 1016 ,,
1 ,, (American = 2000 ,,) = 907·2 ,,
1 gramme (g) (= weight of 1 cubic centimetre of water at 4°C.) = 15·432 grains = 0·0022046 lbs.
1 kilogramme (kg.) = 2·204622 lbs.
1 quintal (100 kg.) = 1·968 cwt.
1 metric ton (1000 kg.) = 0·9842 British ton.
1 litre water at 4°C. = 1 kilogramme.
1 kilogramme = 981,000 dynes.
1 dyne = 1·01979 milligram.
1 megadyne = 1,000,000 dynes = 2·248 lbs.

5. Weight and Area.

1 lb. per sq. foot = 4·8826 kg. per sq. metre.
1 ,, ,, inch = 0·0703 ,, centimetre.
1 ,, ,, foot = 479 dynes ,, ,,
1 kilogramme per sq. cm. = 14·223 lb. per sq inch.
1 kilogramme per sq. metre = 4·8826 lb. per sq. foot.
1 mm. mercury at 0°C. = 0·0013596 kg. per sq. cm.
1 inch mercury = 0·4912 lb. per sq. inch
= 0·034534 kg. per cm^2.

6. Weight and Volume.

1 cubic foot per lb. = 62·43 litres per kg.
1 litre per kg. = 0·01602 feet per lb.

(To convert feet per lb. roughly into litres per kg. multiply by 1000 and divide by 16. To convert litres per kg. into feet per lb., multiply by 16 and divide by 1000)

1 lb. per cub. foot = 16·02 kg. per cubic metre.

7. Work or Energy.

1 erg = 1 dyne-centimetre = 7·376 × 10^{-8} ft. lbs.
1 joule = 1 × 10^7 ergs = 0·7373 ft. lb.
= 0·2389 gr. cal.
= 0·000948 B.T.U.
= 0·0002778 watt hour.
1 watt second = 10,000,000 ergs.
1 kilowatt hour (Board of Trade unit) = 1000 watt hours.
1 foot-pound per second = 1·355 watts
1 kilogrammetre per second = 9·805 ,,
1 metric horse power = 0·735448 kilowatt.
1 British horse power (33,000 ft. lbs. per minute)
= 0·745650 kilowatt
1 cubic foot of water falling 1 foot per second
= 0·0846 kilowatt.

1 cubic metre of water falling 1 metre per second
= 9·806 kilowatt.

1 kilowatt = 1·34 h.p. (British) = 44256·7 ft. lbs. per min.

1 watt = 44·26 ft. lbs. per minute.

8. Thermal.

A B.T.U. (British Thermal Unit) is the heat required to raise the temperature of 1 lb. of water 1° Fahr.

A kilogramme-Calorie is the heat required to raise the temperature of 1 kg of water 1°C.

A gramme-Calorie is the heat required to raise the temperature of 1 gramme of water 1°C.

1 B.T.U. = 0·252 kg-calorie = 252 gr.-calories.
1 „ = 1058 joules = 778 ft. lbs.
1 kg-Calorie = 3·968 B.T.U.
= 426·9 kilogrammetres.
= 3080·9 ft lbs.
= 4200 joules.
1 gr.-calorie = 0·003968 B.T.U.
= 0·4269 kilogrammetres.
= 3·0809 ft. lbs.
= 4·2 joules.

1 gr-Calorie per second = 4·186 watts.
1 kg-Calorie per minute = 69·769 watts.
1 kg-Calorie = 1·16282 watt hours.
1 B.T.U. = 0·293 watt hours.
1 B.T.U. per lb. = 0·55559 kg.-cal. per kilog.
1 kg-Cal. per kg. = 1·8 B.T.U. per lb.

9. Mean Specific Heats (degrees are Centigrade).

Lime (CaO) = Molecular heat 11·4 at 0° + 0·001 t (Gin).
„ = Specific heat 0·1715 at 0°F. + 0·00007
(Richards).

Limestone (marble) ($CaCo_3$)	Specific heat	0·2099 at 23°-98°	(Regnault).
,, (calcite)	,,	0·2086 at 20°-100°	,,
,, (marble)	,,	0·212 at 22°-100°	(Molinari).
Coal	,,	0·2040	,,
Coke	,,	0·203	,,
Charcoal, wood	,,	0·1935 at 0°-100°	,,
Graphite	,,	0·1604 at 10°	,,
,,	,,	0·2966 at 200°	,,
,,	,,	0·4670 at 977°	,,
Carbon (amorphous)	,,	0·1567 at 0°+0·00036 t for temperatures under 250°; 0·2142+0·000166 t for temperatures of 250° to 1000°; and $0{\cdot}5-\frac{120}{t}$ for t over 1000°.	
Carbon	,,	0·355+0·00006 t	(Violle).
,, (retort)	,,	0·1960 at 24° to 70°	(Wulner).
Iron Oxide (Fe_3O_4)	,,	0·1678 at 24° to 100°	(Molinari.)
,,	,,	0·1447+0·000188 t	(Regnault and Richards).
,, (Fe_2O_3)	,,	0·1456+0·000188 t	(do. do.)
Silicon Oxide (SiO_2)	,,	0·1833+0·000077 t	(do. do.)
Magnesium ,, (MgO)	,,	0·244	(Berthelot).
,, ,, ,,	,,	0·2440 at 24°-100°	(Regnault).
,, ,, ,,	,,	0·2420 + 0·000016 t	(assumed by Richards).
Aluminium Oxide (Al_2O_3)		0·2081+0·0000876 t	(Regnault).
Nitrogen, one kg.		0·2405+0·0000214 t	(up to 2000°) (Richards).

Oxygen, one kg.	0·2104 + 0·0000187 t (up o 2000°) (Richards).
Hydrogen ,,	3·370 + 0·0003 t (up to 2000°) (Richards).
Carbon Monoxide (CO), one m^3	0·303 + 0·000027 t (up to 2000°) (Mallard and Le Chatelier).
Carbon Dioxide (CO_2), one m^3	0·37 + 0·00022 (up to 2050°) (calculated by Richards).

10. Weights of Gases (Richards).

(At 0°C. and 760 mm. barometric pressure.)

Hydrogen—H_2—Molecular Weight 2, weight per m—0·09 kg.

Water vapour—H_2O—Molecular Weight 18, weight per m^3—0·81 kg.

Nitrogen—N_2—Molecular Weight 28, weight per m^3——1·26 kg.

Oxygen—O_2—Molecular Weight 32, weight per m^3—1·44 kg.

Carbon Monoxide—CO—Molecular Weight 28, weight per m^3—1·26 kg.

Carbon Dioxide—CO_2—Molecular Weight 44, weight per m^3—1·98 kg.

Marsh Gas—CH_4—Molecular Weight 16, weight per m^3—0·72 kg.

Air, weight per m^3—1·293 kg. (at 0°C. and 760 mm.)

Air, weight per cub. ft.—1·293 oz. (av.).

11. Heats of Formation (Richards),

(Reactions at 15°C.)

Lime (CaO)	131,500 per molecule.
Limestone ($CaCO_3$)	273,850 ,,
Magnesia (MgO)	143,400 ,,

Silica (SiO_2)	180,000	per molecule.	
Carbon Monoxide (CO)	29,160	,,	
Carbon Dioxide (CO_2)	68,040	,,	(CO to CO_2).
,, ,, ,,	97,200	,,	(Carbon to CO_2)
Methane (CH_4)	22,250	,,	
Acetylene (C_2H_2)	−54,750	,,	
Water (H_2O)	70,400	,,	(Solid).
	69,000	,,	(Liquid).
	58,060	,,	(Gas).
Iron Oxide (Fe_3O_4)	270,800	,,	
,, (Fe_2O_3)	195,600	,,	
,, (FeO)	65,700	,,	
Alumina (Al_2O_3)	392,600	,,	
Aluminium Carbide	232,000	,,	
Calcium Carbide	−6,250	,,	

12. Heat Resistivities.

(C. Hering, Metall. and Chem. Eng., December, 1911).

	Resistivities in thermal Ohms.	
	Per in. cu.	*Per cm. cu.*
Air, at 0°	1700	4320
Air, at 20°—155°	143	364
Aluminium, 0°—100°	0·27	0·69
Anthracite coal	317	803
Asbestos, 20°—155°, 8·1% solid matter	139	353
Bauxite brick	28·5	72·4
Brass, 0°—100°	0·36	0·92
Brick, building, about 1000°	29	72
Brick, dust, sifted	204	518
Carbon, electrode mean, 100°—360°	1·05	2·7
,, ,, ,, 100°—942°	0·72	1·9
,, ,, graphite—see graphite		
Carborundum brick, about 1000°	4·1	10·3

Charcoal - - - - -	723	1840
,, pine, 20°—155°, 11·9% solid matter - - - -	494	1260
Chromite brick, about 1000° - -	16	42
Copper—cast - - - -	0·12	0·29
,, —rolled - - -	0·11	0·28
Fire brick, mean for 0°—500° -	67	171
,, ,, 500°—1300° -	23	57
,, ,, 0°—1300° -	30	77
,, about 1000° - -	22	57
Fossil meal—see infusorial earth.		
Graphite electrode, Acheson (mean), 100°—914° - - -	0·32	0·82
Infusorial earth, 21°—175° - -	415	1050
Iron—cast, 30° - - -	0·63	1·6
,, —wrought, 0° - - -	0·46	1·2
Kieselguhr—see infusorial earth.		
Limestone, ordinary - - -	20	51
,, fine-grained grey marble -	9·8	25
,, coarse grained white marble	12	31
,, marble, ordinary, 30° -	19	48
Magnesia, brick, about 1000° - -	13	34
,, calcined, 21°—175° -	572	1450
Magnesium, carbonate, 85°/o, 20°—188°	537	1370
Mineral wool, 21°—175° - -	737	1870
Pumice stone - - - -	187	477
Sand—coarse, 20°—155°, 52·9°/o solid matter - - - -	110	280
,, fine, 20°, 51·4 solid matter -	109	276
,, quartz, fine - - -	718	1820
Silica brick, about 1000° - -	47	120
Slate, 94° - - - -	26	67

NOTE.—The thermal ohm is the resistance causing a drop of 1°C. for each watt of heat flow. To find the conductivity, take the reciprocal of the resistivity; in other words, divide 1 by the resistivity figure given above.

11. Electric Resistivities.

Electrode graphite, at a temperature difference between the two ends of 3000° is 0·00032 ohm per inch cube = 0·000812 per cm. cube.

Electrode carbon under same conditions as above 0·00072 per inch cube, or 0·00183 per cm. cube. Ratio of carbon resistance to graphite therefore 2·25 to 1.

(C. A. Hansen, Electrochemical and Metallurgical Industry, Dec. 1909.)

INDEX.

Abnormal workings of certain carbide, 97.
Accidents in opening drums, 71.
Acheson's graphite, 50, 178.
American type of drum, 70.
Analysis of anthracite, 82, 86.
  ,, anthracite ash, 84, 87.
  ,, carbide, 142.
  ,, charcoal, 177.
  ,, coke, 89.
  ,, dust, 145.
  ,, electrodes, 140.
  ,, furnace charge, 140.
  ,, furnace gases, 143.
  ,, furnace slag, 147.
  ,, gas from anthracite, 87.
  ,, limestone, 107.
  ,, raw materials, 140, 149.
Anthracite—America, 86.
  South Wales, 81.
  Ireland, 82.
Apparatus for testing for phosphorus, 67.
Apparatus for testing for quick generation, 69, 199.
Arsenic in limestone, 106.
Ash of anthracite, 84, 87.
  ,, coke, 88.

Blast furnace gas, utilisation of, 121.
British Acetylene Association, Phosphine in Acetylene, 85.
British Acetylene Association, carbide regulations, 185.
Burning Limestone, coal required, 127.
Burning Limestone, cost of production, 129, 130.
Busbars, arrangement of, 154.
  ,, loss in, 155.

Cables and busbars, 155.
  ,, ,, loss in, 155.
Carbide furnace, theoretical heat balance, 137.
Carbide complaints, common causes of, 197.
Carbide testing for quick generation, 69.
Carbon, for the charge, 78.
  ,, holders, top, 44.
  ,, ,, bottom, 40.
  ,, loss of in furnace, 146.
  ,, monoxide, saving of, 31, 164.
Carbic, experiments on, 203.
Characteristic curves of furnace, 171.
Charcoal, analysis of, 177.
  ,, as raw material, 78.
  ,, consumption of, 78.
  ,, consumption of, electrode with, 174.
Closed furnaces, 31, 32.
Coal (mineral) as raw material, 86.
  ,, analysis of, 82. 86.
  ,, production with, 140.
  ,, percentage of ash and phosphorous, 81.
Coke, analysis of, 89.
  ,, as raw material, 87.
  ,, German, 89.
  ,, advantages and disadvantages, 88, 90.
  ,, effect of iron in, 90.
  ,, production with, 140.
  ,, specific heat, 212.
Complaints, 197.
Conductivity (thermal) of electrodes, 52.
Conductors, loss in, 154, 163.
Consumption of electrodes, 174, 175.
  ,, raw materials, 140.
Contact limekiln, 73.
Continuous current, 35, 170.
Cooling, loss through, 151, 152.
Cost of manufacture, 109, 114.
  ,, producing carbide, 111, 112.
C O Recorder, 76.
Cranes for upper electrodes, 54, 55, 56.
Crushers for carbide, 57.
  ,, raw materials, 60.
Current, direct and alternating, 35.
  ,, density, carbon electrodes, 49.
  ,, ,, busbars, 155.
Cyanamide, carbide dust for, 57.

Decomposition of Acetylene, 198.
Design of factory, 15.
Direct current, 35, 170.
Dissolved Acetylene, 57.
Drums, cost of making, 182.
  ,, plant for making, 70.
  ,, thickness of plates, 180.
  ,, types of, 179.
Dust, analysis of furnace, 145.
  ,, caused by crushers, quantity of, 57.
  ,, from furnaces, 145.
  ,, loss in, 58, 111, 145.
  ,, use of, 57.

Electric energy, cost of, 119.
,, furnaces, classification, 21.
,, path of gases, 8.
,, types of, 20.
,, supply, 117.
Electrodes, consumption of, 174.
,, eating away of, 4.
,, heat conductivity of, 52.
,, heat losses through, 150.
,, specific resistance of, 50
Electrode holders, bottom, 40.
,, ,, ,, cooling, 42.
,, ,, top, 44.
,, ,, disadvantages, 28.
Equation, commercial of production, 149.
Equipment of Factory, 16.
European type of drum, 71.
Experiments on carbide, 97.

Factory, arrangement of, 14.
,, chief appliances, 18.
,, ,, factors, 10.
,, choice of site, 9.
,, cost of, 11.
,, design of, 15.
,, equipment, 16.
,, testing carbide in, 196.
,, workmen required for, 15.
Ferro-silicon in carbide, 91.
Formula for carbide, 1, 146.
Foster, use of producer gas, 122.
Furnaces, characteristic curves of, 171.
Furnaces, cost of, 30.
,, covered in, 31.
,, heat losses in, 150.
,, ingot or semi-ingot type, 34, 35.
,, lining and body, 37, 38.
,, single-phase, 20, 29.
,, three-phase, 21.
,, various types of, 20.
,, with horizontal electrodes, 34.

Gas furnace, analysis of, 143.
Gas, influence on production, 134.
,, from anthracite, analysis of, 87.
,, fired limekiln, 73.
,, and steam power, 120.
Gases, weights of, 143.
Gas yield, corrections for pressure and temperature, 193.
,, effect of lime on, 194.
,, effect of carbide size on, 188.
,, methods of improving, 189.
Gatehouse, apparatus for phosphorus test, 67.
,, experiments on carbide, 97, 202.

Haze, cause of, 200.
Heat, balance of furnace, 137.
Heats of formation, 213.
Heat losses in furnace, 150.
,, effect of water cooling on, 152.
,, through conduction and radiation, 158.
,, through top of open furnace, 160.
Heat resistivities, 214.
Holders, carbon, top, 44.
,, ,, bottom, 40.
,, requirements of a good, 47.
Horrie furnace, electrode consumption of, 178.
Hydro-electric station, cost of, 119.
Hydrogen, effect on carbon-electrodes, 7.

Impurities, loss of current through, 23.
,, in carbide, 148.
,, in acetylene, 202.
Ingot carbide, furnaces for, 34.
Italian type of electrode holder, 46.
Iron, in limestone, 103.
,, pyrites, in coke, 90.

Laboratory equipment, 65.
Labour, cost of, in manufacture, 112.
Lever-lid type of drum, 71.
Lime kiln, cost of building, 77.
,, selection of, 76.
,, types of, 73.
,, working results, 127.
Lime, cost of, 129.
,, loss in dust, 131.
Limestone, analysis of, 107.
,, aluminium compounds in, 95.
,, arsenic in, 106.
,, general remarks on, 92.
,, iron in, 103
,, magnesium in, 94.
,, maximum impurities allowable, 106.
,, phosphorus in, 103.
,, physical requirements, 108.
,, silicon in, 96.
,, sulphur in, 106.
Losses, heat, in carbons, 150.
,, in furnaces, 150.
,, ohmic, in busbars, 154.
,, ,, in carbons, 150.
Low production, reasons for, 24.

Magnesia, effect of excess in carbide, 102.
,, in coal, 84.
,, in limestone, 81, 93, 94
Magnesite, for bottom holder, 48.
Manufacture, chief factors for successful, 10.
,, results of, 109.
,, probable cost of, 110.

Materials, used in carbide manufacture, 78.
Maximum impurities allowable in limestone, 106.
Moisture in coke, 88.

Newcastle coke, 89.

Ohmic resistance, loss through, 154.
,, ,, of carbon at various temperatures, 51.
Overheating in acetylene generators, 198.

Packing drums, cost of making, 182.
,, ,, different types of, 179.
Percentage of carbide and gas yield, 190.
Phosphorus in anthracite, 84.
,, in acetylene, 85.
,, in carbide, 200.
,, detection of, 67.
,, in limestone, 103.
,, maximum figure in raw materials, 104.
,, spontaneous ignition through, 105.
Physical requirements of limestone, 108.
Plant for drum making, 72.
Power, cost of, 113, 119.
,, plant, 117.
,, ,, losses in, 118.
,, capital cost of, 120.
,, factor, 165.
,, effect of current on, 169.
,, devices for improving, 170.
Power stations, 117.
Preheating raw materials, 52.
Producer gas, for power, 123.
Production, effect of increase of lime on, 194.
,, per kilowatt day, 135.
Purifiers, tests with, 201.
,, removal of sulphur, 84.

Quality of carbide, regulations, 185.
"Quick" carbide, 35, 197.

Radiation, heat loss through, 150, 158.
Raw materials, amount required, 140.
,, analysis, 140.
,, carbide produced from, 142.
,, gases produced from, 152.
,, production from, 149.
Reaction in carbide furnace, 6.
Recovery of carbon-monoxide, 31.
Regulation of furnaces, 26.
Resistance (ohmic) loss through, 154.
Resistance loss through contacts, 155.
Results of manufacture, 109.
Returnable drums, 179, 183.

Screeners, for carbide, 61.
Screw top drums, 70.
Siemiens type of electrode holder, 44.
Silicon, in coal and coke, 84, 90.
,, in limestone. 96.
Size of raw material, 60.
Skin effect, 3.
Slag, analysis of furnace, 147.
Smell of acetylene, cause of, 205.
South Wales coke, 89.
Specific resistance, of electrodes, 50.
,, heats, various, 211.
Spontaneous ignition through phosphorous, 105.
Sulphur, relative proportions in anthracite and coke, and acetylene, 83.
Sulphur in limestone, 106.
Swedish type of electrode holder, 45.

Tables, of constants, &c., 208.
Temperature, of formation of carbide, 136, 137, 149.
,, of generation of acetylene, 198, 201.
Testing carbide, 65, 185, 196, 199.
Tests, for phosphorous, 85.
Theoretical production of a furnace, 138.
Thermal conductivity of electrodes, 52.
,, constants, 211.
,, of furnace walls, 158.
Three-phase furnaces, 21.
,, electrode consumption of, 26.
,, comparative cost of working, 27.
Tins for carbide, 184.
Transformers, 118.
,, position of, 17, 154.
Transport appliances, for raw material, 63
Transport appliances, for electrodes and raw carbides, 64.

Upper electrode holders, requirements, 47.

Volume of gas, effect of pressure and temperature on, 191.

Water-cooling, loss through, 153.
Water-power, cost of, 120.
Weights of gases, 213.
Westphalian coke, 89.
Wood overcasks for drums, 181.
Workmen, number required, 112.

Zone of fusion, 22.

RAGGETT & Co., Printers, 30, Red Lion Square, London, W.C.

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

AN INITIAL FINE OF 25 CENTS
WILL BE ASSESSED FOR FAILURE TO RETURN THIS BOOK ON THE DATE DUE. THE PENALTY WILL INCREASE TO 50 CENTS ON THE FOURTH DAY AND TO $1.00 ON THE SEVENTH DAY OVERDUE.

APR 2 1939
APR 21 1939
MAY 25 1940
MAR 26 1941 M
3-30
Gardiner
APR 14 1941 M
4-13
Cohn
APR 23 1941 M

Jones
6/19
JUL 15 1941
DEC 8 1941 Y
APR 22 1943
JAN 18 1944
DEC 12 1944
Dec 26
LIBRARY USE
Jan 7
FEB 14 1951
LIBRARY USE

LD 21-95m-7,'37

YC 94069

358214 TP770
B6

Bingham

UNIVERSITY OF CALIFORNIA LIBRARY